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in
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ABSTRACT

An experimental investigation of the effect of variation in flow angle on convection heat transfer and frictional resistance in a tube bank is undertaken for three systematically varied geometries. Data taken by previous investigators for a fourth geometry is included in the analysis.

Design-oriented curves and equations derived from analysis of the results are presented. The curves give the value of an inclination factor which may be used as an additional factor in the modified Grimison equation.

Similar design oriented curves are presented which give an inclination factor which is in effect the ratio of friction factor at any angle to that for cross flow. Equations for the friction factor at ninety degrees are derived.

Extensive use is made of electronic digital computers for data reduction and analysis.

NOMENCLATURE AND DEFINITIONS

Program Listing	Engineering Symbol	Definition
A	A	The inclination factor equation intercept in the convection heat transfer regression analysis.
AK	K	Flow coefficient for a sharp-edged thin plate orifice.
ANRE	N_{RE}	Reynolds number through the thin plate orifice.
ANNU	N_{NU}	Experimental Nusselt Number, Cross flow.
ARGFAC	F_A	Arrangement factor in the modified Grimison equation.
B	B	Coefficient of Reynolds Number in the convection heat transfer regression analysis.
BK	K	Flow coefficient for sharp-edged thin plate orifice calculated by data reduction program.
BNRE	N_{RE}	Reynolds Number in the tube bank where transport data is a function of TF
BNNU	N_U	Experimental Nusselt Number, any angle
C	–	Quotient of AK and BK taken so as to always be less than unity.

Program Listing	Engineering Symbol	Definition
CNRE	N_{RE}	Reynolds Number in the tube bank where transport data is a function of TFF.
CNNU	N_{NU}	Nusselt Number calculated by Colburn equation.
CONST	K	The coefficient of Reynolds Number in the frictional resistance analysis.
CPD	c_p	Specific heat of dry air at constant pressure.
CPH	c_p	Specific heat of water at constant pressure.
CPW	c_p	Specific heat of wet air at constant pressure.
DHF	-	Pressure drop across the thin plate orifice.
DIAFAC	$\left(\frac{D_H}{D_T}\right)^{0.20}$	Two tenths power of the ratio of hydraulic diameter to tube diameter.
DNRE		Floating point mode equivalent of NRE.
DP	-	Pressure drop across the tube bank in inches of water.
ENRE	N_{RE}	Reynolds Numbers used in computation of friction factor from frictional resistance analysis.

Program Listing	Engineering Symbol	Definition
EXPO	x	Exponent of Reynolds number in the frictional resistance analysis
FRICT	f	Friction factor computed from parameter developed by frictional resistance analysis.
FRIFAC	f	Friction factor computed in data reduction program.
-	h_f	Convection heat transfer coefficient.
IDO	d	Diameter of the thin plate orifice
IRCN, RNCD	-	Run code number for identification.
Equation	k	Thermal conductivity of air
KASES	-	Maximum number of data sets in any run of the data reduction or frictional resistance analysis programs, index of controlling DO Loop in each.
LAF	-	Back pitch indicator.
LANGLE	-	Angle indicator.
LGF	-	Arrangement indicator index of DO Loop representing the sequential number of a set of data being processed in data reduction program.
M	-	Exponent of Reynolds Number in convection heat transfer analysis.

Program Listing	Engineering Symbol	Definition
NRE	-	Index of DO loop in frictional resistance analysis for computation of frictional resistance from parameters computed in the program.
NUMB	-	Index analysis program of DO Loop in frictional resistance. Maximum number of data points in a data set, in the frictional resistance analysis.
p_1	p_1	Pressure above atmospheric ahead of the thin plate orifice
PB	p_b	Barometric pressure
RHO	ρ	Air density
SPHU	X	Specific humidity
TAVG	T_{AVG}	Average or bulk temperature of air in the tube bank.
TE	T_2	Exhaust temperature; temperature of air after passing through the tube bank.
TF	T_f	Film temperature, mean between bulk temperature and tube surface temperature.
TFF	T_f	Film temperature, for frictional resistance calculation, based on T_S - C (LMTD)

Program Listing	Engineering Symbol	Definition
THUMB	-	Floating point mode equivalent of NUMB
TT	T_t, T_s	Tube surface temperature
V	-	Intermediate quantity calculated in the data reduction program.
WAO	W	Weight rate of flow of air through the orifice.
XCON	$\log_e K$	Natural logarithm of CONST.
Y	Y	Net expansion factor, ratio of the flow coefficient of a gas to a liquid at the same Reynolds Number.
Z	-	Intermediate quantity calculated in the data reduction program.
-	μ	Dynamic viscosity of air.
-	θ	Angle of inclination of tube bank; cross flow is ninety degrees, parallel flow zero degrees.

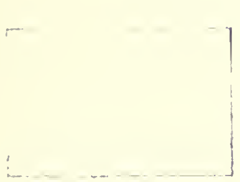
DEFINITIONS OF COMPUTER ORIENTED TERMINOLOGY

Fixed-point variable - a variable written without a decimal point using the digits o, 1.....9; may be positive or negative.

Floating-point variable - a variable written with a decimal point using the digits o, 1....9, with an optional preceeding plus or minus sign. The variable value may contain a multiplier which is ten to some power, the multiplier being represented by the symbol E and the power of ten.

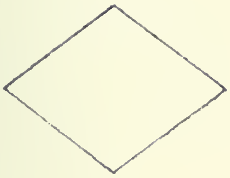
DO loop - a method of performing the same calculation with different data by repeatedly executing the statements following the DO statements the number of times indicated by an index.

BLOCK DIAGRAM SYMBOLS



Processing a group of program instructions which perform a processing function.

Input or output - any function of any input or output device.

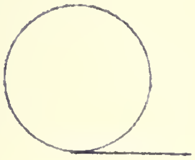


Decision or Logic - The decision or logic function documents points in the program where a branch to alternate points is possible.

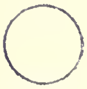
Predefined process - a group of operations not detailed by the particular program.

Terminal - the beginning end or a point of interruption of a program.

An off-page connector



Magnetic Tape



Connector

RUN CODE NUMBERS

A system of coding data points to reflect in a single multi-digit number, tube geometry, angle of inclination and sequential number of the test run was developed. The run code number is a four digit number; the first number indicating tube geometry, the second indicating the angle of inclination, and the third and fourth numbers indicating the sequential number of the run.

Tube geometry codes:

Code	Description
1	Staggered tubes, ST = SL = 1.5 D_t (Smith-Kiss and Bond-Wallin data)
2	In-line tubes ST = SL = 1.5 D_t
3	Staggered tubes ST = 1.5 D_t SL = 2.0 D_t
4	In-line tubes ST = 1.5 D_t SL = 2.0 D_t

Angle codes:

Code	Description
3	30 degree angle of inclination
4	45 degree angle of inclination
6	60 degree angle of inclination
7	75 degree angle of inclination
9	90 degree angle of inclination

Example: 1704

tube geometry 1, ST = SL = 1.5 D_t, staggered tubes.

seventy five degree angle of inclination,

fourth run

INTRODUCTION

While adequate empirically derived design information is available for heat transfer equipment where the tube banks are parallel to or normal to the flow of the fluid being heated or cooled, little information exists for the case where the tubes are inclined at some angle to the fluid flow. The case of tubes at an angle to fluid flow is not uncommon particularly in marine boiler convection banks. It is the purpose of this thesis to investigate the effect of variation in flow angle on convection heat transfer and frictional resistance in a tube bank using a model scale apparatus, and to develop constants which will be useful to the designer of heat transfer equipment.

The relationship originally developed by Grimison [1]* and later modified by the transport data obtained by Justi and Leuder [2] will be used as the basic convection heat transfer relationship where the tube banks are inclined at ninety degrees to the fluid flow. A factor F_θ will be developed which, when included in the modified version [3] of this equation will give it the form:

$$\frac{h_f d_t}{k} = 0.292\, F_A F_D F_\theta\, f_t f_a \left(N_{Re}\right)^{0.60} \left(N_{Pr}\right)^{1/3}$$

The factor F_θ will be obtained from design curves, and when so used will give a modified value of Nusselt Number $\frac{h_f d_t}{k}$ for the tubes inclined at an angle θ to fluid flow.

Concurrently, with the investigation of the effect of variation in flow angle on convection heat transfer the effect on frictional resistance as expressed by the Fanning type friction factor will be determined.

*Numbers in brackets designate references listed at the end of text.

The availability of electronic computers makes possible more accurate reduction and analysis of experimental data than has been possible before. In addition, they permit a greater number of calculations to be carried out in a short time. Thus a systematic series of geometries will be tested by varying the longitudinal tube pitch and tube arrangement.

THEORY

Effect on Convection Heat Transfer

The transfer of heat by a fluid passing through a tube bank is by the mechanism of forced convection in turbulent flow. The quantity of heat transferred through the stagnant fluid film or thermal boundary layer contiguous to the tube is a function of the following quantities:

a) a characteristic length, taken in this development as the outside diameter of the tubes, D_t.

b) the coefficient of convection heat transfer, h_f, between the fluid and the tube surface.

c) the thermal conductivity, k, of the fluid.

d) the specific heat, c_p, of the fluid at constant pressure.

e) the dynamic viscosity, μ, of the fluid.

f) the mass flow of the fluid, G.

The convection heat transfer coefficient may be expressed as a function of the other quantities:

$$h = f\ (Dt,\ K,\ cp,\ \mu\ ,\ G)$$

The choice of a characteristic length and of a temperature at which to evaluate those temperatures dependent physical properties is open to some discussion. When fluid flows across a single tube the outside diameter of the tube is the most logical choice, however in a tube bank the flow is effected by

the clearance between tubes and other definitions of characteristic length have been suggested.

To preserve consistency with Pierson,[illegible] Grimison[1] and Huge[5] and because other definitions provide no proven advantage the outside diameter of the tube will be used. Similarly various definitions of the temperature at which to evaluate physical properties have been suggested.

That which is consistent with the work mentioned above and which is most logical for forced convection heat transfer is the temperature of the fluid film. As there is a variation in fluid film temperature through its thickness the film temperature is defined as the arithmetic mean between the bulk temperature and the tube surface temperature. Likewise the bulk temperature varies through the tube bank and is defined as the arithmetic mean of the inlet and exhaust temperatures.

The exact mechanism of forced convection heat transfer is not fully understood so that while analytical methods can sometimes be used, semi-empirical or empirical relationships are more reliable. The development of empirical relationships is assisted by the derivation of dimensionless groups of the physical qualities discussed above.

These groups may be derived by the methods of dimensional analysis. The applicable dimensions are:

L for length

T for time

M for mass

H for heat energy

ϕ for temperature

As heat is equivalent to mechanical work it can be replaced by (force) x (resistance) or $H = ML^2 T^{-2}$. The dimensions of the remainder of the physical properties may be expressed as:

$$D_t = L$$
$$h_f = MT^{-3}\phi^{-1}$$
$$k = MLT^{-3}\phi^{-1}$$
$$c_p = L^2T^{-2}\phi^{-1}$$
$$\mu = ML^{-1}T^{-1}$$
$$G = ML^{-2}T^{-1}$$

If the Buckingham Pi Theorem is applied, the following matrix is developed:

$$\begin{array}{c} \\ M \\ L \\ T \\ \phi \end{array} \begin{array}{c} \begin{array}{cccccc} D_t & h_f & K & c_p & \mu & G \end{array} \\ \begin{bmatrix} 0 & 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 2 & -1 & -2 \\ 0 & -3 & -3 & -2 & -1 & -1 \\ 0 & -1 & -1 & -1 & 0 & 0 \end{bmatrix} \end{array}$$

From this matrix three dimensionless relations which have proved useful in heat transfer work are derived. These are:

$$\frac{h_f d_t}{k} = \frac{MT^{-3}\phi^{-1}\ L}{MT^{-3}\phi^{-1}\ D} = \text{Nusselt number},$$

which may physically be interpreted as the ratio of the characteristic length to a stationary fluid layer conducting heat at the same rate under the same temperature difference;

$$\frac{GD_t}{\mu} = \frac{ML^{-2}T^{-1}\ L}{ML^{-1}T^{-1}} = \text{Reynolds number},$$

which may be interpreted as the ratio of inertia force to viscous force and:

$$\frac{c_p\mu}{k} = \frac{L^2T^{-2}\phi^{-1}\ .\ ML^{-1}T^{-1}}{MLT^{-3}\phi^{-1}} = \text{Prandtl Number}$$

which is the ratio of two constants of molecular transportation. The relationship is usually written in terms of power functions as:

$$\frac{h_fD_t}{k} = A\left(\frac{GDt}{\mu}\right)^a \left(\frac{c_p\mu}{k}\right)^b$$

where the coefficient A and the exponents a and b are constants.

By correlation of empirical data where the fluid flow is normal to the tube bank the above equation has been shown to be:

$$\frac{h_fD_t}{k} = 0.292\ F_AF_D \left(\frac{GD_t}{\mu}\right)^{0.60} \left(\frac{c_p\mu}{k}\right)^{1/3}$$

where F_A and F_D are empirical correlations known as arrangement factor and depth factor respectively. The arrangement factor is a function of tube arrangement, staggered or in-line, longitudinal and transverse spacing and Reynolds Number. The depth factor is a function of the number of rows in the tube bank. The depth factor determined by Grimison becomes unity for ten or more rows.

Colburn[6] has shown that for fluid flow parallel to the tube surface:

$$\frac{h_f D_H}{K} = 0.023 \left(\frac{GDH}{\mu}\right)^{0.80} \left(\frac{c_p \mu}{K}\right)^{1/3}$$

Where D_H is the hydraulic diameter. In order to be able to make a direct comparison with flow normal to the tubes the above expression may be written in terms of tube diameter.

$$\frac{h_f D_t}{k} = 0.023 \left(\frac{GD_t}{\mu}\right)^{0.80} \left(\frac{D_H}{D_t}\right)^{0.20} \left(\frac{c_p \mu}{k}\right)^{1/3}$$

For cases where the fluid flow is neither normal nor parallel to the tube surface, but inclined at some angle theta to it, the rate of heat transfer as indicated by the value of Nusselt Number should lie somewhere between that for normal flow or cross flow, and parallel flow. It should be possible to express the effect of the inclined flow on forced convection heat transfer in one of two ways either as:

1) a modification to the exponent of Reynolds Number, i.e.;

$$\frac{h_f D_t}{k} = 0.292\, F_A F_D \left(\frac{GD_t}{\mu}\right)^{0.60\, f(\theta)} \left(\frac{c_p \mu}{k}\right)$$

where f (θ) represents a function of the angle of inclination, or

2) as an additional multiplying factor:

$$\frac{h_f D_t}{k} = 0.292\, F_A F_D\, f(\theta) \left(\frac{GD_t}{\mu}\right)^{0.60} \left(\frac{c_p \mu}{k}\right)^{1/3}$$

An analytic prediction of the effect of flow angle on convection heat transfer would be at best uncertain. As the earlier work with which this work is to be consistent is an empirical correlation, no theoretical prediction will be attempted. Instead, data derived from the test apparatus will be correlated with the empirical equation to produce a modifying factor which is a function of the angle of inclination.

Effect on Frictional Resistance

The frictional resistance of a fluid flowing across a tube bank is customarily treated by an equation of the general Fanning type wherein the pressure drop is treated as being caused by flow through a series of orifices formed by successive major restrictions in the flow path. By methods of dimensional analysis similar to those described above for convection heat transfer a dimensionless friction factor, f, may be derived which is a function of Reynolds Number only:

$$f = C\left(\frac{GD_t}{\mu}\right)^X$$

Where the coefficient C and the exponent X are constants. This equation may be modified to permit the use of convenient quantities without reducing its soundness:

$$f = \frac{10.84\ (10)^8 \rho DP}{NG^2}$$

where:

10.84 = a constant which includes the effect of the acceleration of gravity in ft. per hr. per hr. and a head conversion factor from pounds per square foot to inches of water

= air density

DP = pressure drop across the tube bank in inches of water

N = number of major identical restrictions. (in the case of a tube bank N is equivalent to the number of rows of tubes)

G = mass flow

The question of what temperature should be used to determine the properties of the fluid again arises. The temperature has a significant effect on gas density and viscosity which directly effect the friction factor and the corresponding Reynolds Number. Utilization of the mean bulk temperature in the bank has been shown to be unsatisfactory by previous investigators. Empirical developments led to the establishment of the convention that the physical properties be evaluated at a temperature equal to the tube surface temperature minus eight tenths the log mean temperature difference for staggered arrangements or equal to tube surface temperature minus nine tenths the log mean temperature difference for in-line arrangements. The minus sign applies where heat is transferred from heated tubes to a cooler fluid.

As is true with the convection heat transfer the prediction of variation of friction factor with flow angle does not lend itself to analytic prediction. Accordingly no attempt at analytic prediction will be made.

The choice of a purely empirical approach while not as intellectually stimulating as a theoretical development has the distinct advantage of producing results which are reproduceable and can be used with some confidence in the design of heat transfer equipment.

EXPERIMENTAL TECHNIQUE

The technique followed in the investigation is that of forcing air through a bank of heated tubes which are arranged in various geometries and inclined at various angles to the air flow in order to measure changes in parameters indicative of the quantities of heat transferred and the frictional resistance in the bank. Data is obtained for three geometries, all with a pitch normal to the air flow of 1.50 tube diameters. Pitches in the direction of flow are 1.50 and 2.00 tube diameters and the tubes are arranged in staggered and in-line configurations. For each geometry, measurements are taken with the tube bank at angles of 90, 60, 45 and 30 degrees to the air flow. The angle is varied by inclining the tube bank in a test section of constant cross section and length.

The tubes are internally heated by steam, the inlet pressure being controlled so that the tube surface temperature is very near 212 degrees Farenheit. Ambient air is heated by being forced through the tube bank by a steam turbine driven blower. Variations in the mass flow of air are obtained by varying the speed of the supply blower. The mass flow of air is measured by means of a square edged orifice and appropriate manometers. Temperature sensors in the air duct upstream and downstream from the tube bank are used to determine inlet and outlet temperatures. Tube surface temperatures are determined by sensors located on the tube surfaces throughout the bank, generally on the upstream sector of the tube. Tube surface

temperatures used in the computations are then the arithmetic mean of the measured tube temperatures. The principle parameter for determining the effect of frictional resistance is the pressure drop across the tube bank measured by manometers. Transport data is evaluated at appropriate temperatures with a humidity correction obtained by standard psychometric techniques applied to the specific heat.

In addition to the data obtained from the three geometries tested, the data determined by previous investigators has also been included. All this data has been placed through the computation process and analyzed for correlation of both the previous work and the extended investigation.

PROCEDURE FOR REDUCING EXPERIMENTAL DATA

The purpose of the reduction of experimental data is the calculation of Nusselt Numbers, Reynolds Numbers and friction factor. This process may be divided into four parts:

1) calculation of weight rate of flow through the apparatus
2) calculation of Nusselt Number and the corresponding Reynolds Number
3) calculation of friction factor and the corresponding Reynolds Number
4) calculation of Nusselt Numbers by the modified Grimison equation and the Colburn equation.

This section develops in detail the calculation procedure.

1) Weight rate of flow:

The weight rate of flow calculation is perhaps the most complex of those performed. The equation is:

$$WAO = A_2\ (AK)\ Y \sqrt{2g\rho\ (P_1 - P_2)}$$

where:

WAO = weight rate of flow

AK = flow coefficient

Y = expansion factor

g = gravitational constant

ρ = air density

$(P_1 - P_2)$ = pressure differential across the orifice

The method used to obtain weight rate of flow from orifice dimensions and pressure differential is a standard engineering technique and has been developed in detail by both Bond and Wallin[2] and Kiss and Smith;[7] it will not be repeated here.

By combining constants and applying proper unit conversion factors the equation reduces to:

$$WAO = 0.02416\ (IDO)^2\ (AK)\ Y \sqrt{DHF}$$

where:

IDO = orifice meter diameter in inches

DHF = pressure drop across the orifice meter in inches of oil

The expansion factor Y is a function of diameter ratio, ratio of differential pressure to absolute static pressure and the ratio of specific heats. As shown in Appendix D the factor Y can be calculated for each data point by applying an equation of the form

$$Y = 1 - \frac{C_1\ (DHF)}{p_1 - 13.596PB}$$

The flow coefficient, AK, is a function of orifice diameter, diameter ratio, and pipe Reynolds Number. The derivation of the expressions for flow coefficient in Appendix D gives equations of the form:

$$AK = \frac{C_2 + C_3}{\sqrt{ANRE}}$$

However Reynolds Number in the pipe is given by the expression:

$$ANRE = \frac{V\ (IDO)}{\mu}\ (AK)\ C \sqrt{DHF}$$

where:

ANRE = Pipe Reynolds Number

V = Expansion Factor

IDO = Orifice Diameter

μ = Dynamic Viscosity for air, the expression for which was developed in Appendix D and is

$$\mu = (.16\ TI + 112.6) \times 10^{-7}$$

AK = flow coefficient

C = a constant

DHF = differential pressure across the thin plate orifice meter.

It can be seen that flow coefficient and Reynolds Number are mutually dependent and an iterative process must be used to determine satisfactory values for these two quantities. This can be done by first calculating intermediate quantities composed of those factors other than AK which appear in the Reynolds Number expression specifically:

$$V = \left[\frac{2.239}{0.16TI + 112.6} \right] \times 10^{7}$$

and:

$$Y = \frac{1 - C_1\ (DHF)}{p_1 + 13.596PB}$$

A trial value of AK depending upon orifice diameter may be assumed and a corresponding value of Reynolds Number may be calculated:

ANRE = V x Y x AK

This value of Reynolds Number may be used to calculate a second value of flow coefficient which in turn may be used to compute a new Reynolds Number. This process can continue until the comparison of the new value of AK with the previously

calculated value shows that the increase in accuracy does not warrant repetition. This final value of flow coefficient can then be used to calculate weight rate of flow of air through the apparatus.

$$WAO = (86.978)\ (IDO)^2\ (AK)\ (X)$$

When the weight rate of flow has been determined certain other values may be determined. These include: the average temperature in the tube bank in degrees Rankine:

$$TAVG = \frac{TI + TE}{2.0} + 459.69$$

and the specific heat of wet air by the method detailed in Appendix D, the log mean temperature difference:

$$XLMTD = \frac{TE - TI}{LOG_e\left(\frac{TT - TI}{TT - TE}\right)}$$

and film temperature:

$$TF = \frac{\left(\frac{TI + TE}{2.0}\right) + TT}{2.0}$$

When these quantities have been computed everything necessary for the second major calculation step, the computation of Nusselt Number has been completed. The computation of Nusselt Number may then be undertaken.

2) Nusselt Number:

Nusselt Number may be defined as

$$\text{Nusselt Number} = \frac{Q}{S\ (XLMTD)} \cdot \frac{Dt}{K}$$

where:

Q = total heat transferred

Dt = tube diameter

S = total heating surface

XLMTD = log mean temperature difference

k = thermal conductivity of air

The relation for Nusselt Number may then be expressed as:

$$\text{ANNU} = \frac{\text{WAO (CPW) (TE - TI)}}{\text{L}\pi\text{(XLMTD) (0.000024TF + 0.01344)}}$$

where:

Q = WAO (CPW) (TE-TI)

k = 0.000024TF + 0.01344

Dt/S = effective length L x π

by utilizing the interior dimension of the box, minimum possible tube length, and combining constants the equation reduces to:

$$\text{ANNU} = \frac{\text{WAO (CPW) (TE - TI)}}{\text{XLMTD (0.01158TF + 6.4829)}}.$$

For flow in which the tubes are inclined the surface area is increased. The surface area at any angle of inclination is equal to the surface area at ninety degrees divided by the sine of the angle of inclination, thus for angles other than ninety degrees the expression for Nusselt Number becomes:

$$\text{BNNU} = \frac{\text{WAO (CPW) (TE - TI) SINE } \theta}{\text{XLMTD (0.01158TF + 6.4829)}} = \text{ANNU (SINE } \theta)$$

This is the proper value of Nusselt Number for inclined flow and is the one result of the second part of the calculation. It is now necessary to calculate the Reynolds Number through the test section. Reynolds Number may be expressed as:

$$BNRE = \frac{WAO\ (Dt)}{A\mu},$$

where:

A = free flow area through the test section, a projected area which remains constant though the angle is varied

μ = dynamic viscosity of air = $(.16TF \times 112.6) \times 10^{-7}$

The equation reduces to:

$$BNRE = \frac{WAO \times 10^{2}}{(0.046256TF + 32.552)}.$$

With these two results, Nusselt Number and Reynolds Number the second part of the computation is complete.

3) Friction factor

For the frictional resistance calculation some quantities which have not been previously calculated are required.

A new definition of film temperature is necessary. This definition is a function of tube temperature and log mean temperature difference and may be expressed in the form:

$$TFF = TT - C_5\ (XLMTD)$$

where C_5 is either 0.800 or 0.900 depending upon whether the tube geometry is staggered or in-line. A Reynolds Number for

use with the friction factor may be calculated using the value of film temperature just computed:

$$\text{CNRE} = \frac{\text{WAO} \times 10^2}{(0.046256\ \text{TFF} + 32.552)}.$$

The friction factor is expressed as:

$$\text{FRIFAC} = \frac{10.84\ (\text{RHO})\ \text{DP}\ 10^8}{N\left(\frac{\text{WAO}}{A}\right)^2}$$

The density of air is calculated using the equation:

$$\frac{P}{\text{RHO}} = \text{RT in the form}$$

$$\text{RHO} = \frac{(P_1 + 13.596\text{PB})\ 5.1815}{53.349 \quad \text{TFF} = 459.69}$$

When RHO has been obtained the friction factor may be calculated:

$$\text{FRIFAC} = \frac{1.084\ (\text{RHO}) \quad (\text{DP})\ 10^8}{\frac{\text{WAO}^2}{0.1673^2}}$$

4) Nusselt Number by the Grimison Equation

When the friction factor has been obtained, the computation continues to calculate the Nusselt Number by the modified Grimison equation.

The Grimison equation is expressed as:

$$\text{TNNU} = 0.292\ (\text{ARGFAC})\ F_d\ (\text{BNRE})^{0.60} \left(\frac{\text{CPW}\mu}{k}\right)^{1/3}$$

As the test section is ten rows deep the depth factor, F_d, is unity and can be eliminated from the expression. The quantities Reynolds Number, BNRE, and specific heat, CPW are

available from previous work, and analytic expressions in terms of temperature exist for dynamic viscosity and thermal conductivity. It has been shown in Appendix D that the arrangement factor may be expressed as a function of Reynolds Number for specific geometries. With proper substitutions the expression for Nusselt Number becomes:

$$\mathrm{TNNU} = 0.292\ \mathrm{ARGFAC}\ (\mathrm{BNRE})^{.6} \left[\frac{\mathrm{CPW}\ (0.16\mathrm{TF} + 112.6)\ (10^{-7})}{.00024\mathrm{TF} + 0.01344}\right]^{.333}$$

When this value of Nusselt Number has been determined, a factor FTHETA is defined by forming the quotient of the experimental Nusselt Number BNNU, and the Grimison Nusselt Number, TNNU:

$$\mathrm{FTHETA} = \frac{\mathrm{BNNU}}{\mathrm{TNNU}}.$$

When FTHETA has been computed, the computation of Nusselt Number by the Colburn expression is undertaken. The similarity in the Colburn expression and that for the Grimison equation leads to simplifying the calculation by calculating the Colburn Nusselt Number using the previously calculated Grimison Nusselt Number:

$$\mathrm{CNNU} = .023\ (\mathrm{BNRE})^{0.80} (\mathrm{DIAFAC}) \left(\frac{\mathrm{CPW}\mu}{K}\right)^{1/3}$$

where DIAFAC is a conversion factor the tube diameter to hydraulic diameter.

$$\mathrm{TNNU} = .292\ (\mathrm{BNRE})^{0.60} (\mathrm{ARGFAC}) \left(\frac{\mathrm{CPW}\mu}{K}\right)^{1/3}$$

Dividing CNNU by TNNU and solving for CNNU:

$$CNNU = \frac{.07877\ (BNRE)^{0.20}(DIAFAC)\ TNNU}{ARGFAC}.$$

This form is readily digestible by the computer. When CNNU has been computed the calculation of one data point is complete.

When the calculations have been completed for all data points the processing of experimental data is complete and analysis can commence.

ANALYSIS OF CONVECTION HEAT TRANSFER RESULTS

Figures 1 thru 4 are composite plots showing the experimental variation of Nusselt Number with Reynolds Number for each of the four geometries which have been tested. The variation in slope of the plots as the angle of inclination changes indicates that the inclination factor F_Θ is not a simple multiplying constant but is an exponential function of Reynolds Number.

F_Θ is defined as the ratio of the experimentally determined Nusselt Number to the Theoretical Nusselt Number, calculated by the modified Grimison equation, at a particular value of Reynolds Number. Thus for every experimental point a value of F_Θ as Reynolds Number may be plotted.

Rather than plot these values by hand, the data processing facilities at David Taylor Model Basin were utilized to enhance the speed and accuracy of the process. An existing program was modified and used to provide the needed output. This program is described in David Taylor Model Basin Report No. 2037[7] and in Appendix G.

The program takes as input the values F_Θ and the corresponding Reynolds Number plus identifying codes which serve to individualize each of the points. The output is the equation of three lines of regression which are produced by means of the method of least squares. In addition, there is a graphic output which plots the three lines of regression which are determined. Samples of these output forms are included in Appendix G. A complete summary of the regression analysis coefficients is shown on page 42.

COMPOSITE PLOT
VARIATION OF NUSSELT NUMBER
WITH REYNOLDS NUMBER
$S_T = S_L = 1.5 D_T$ STG.

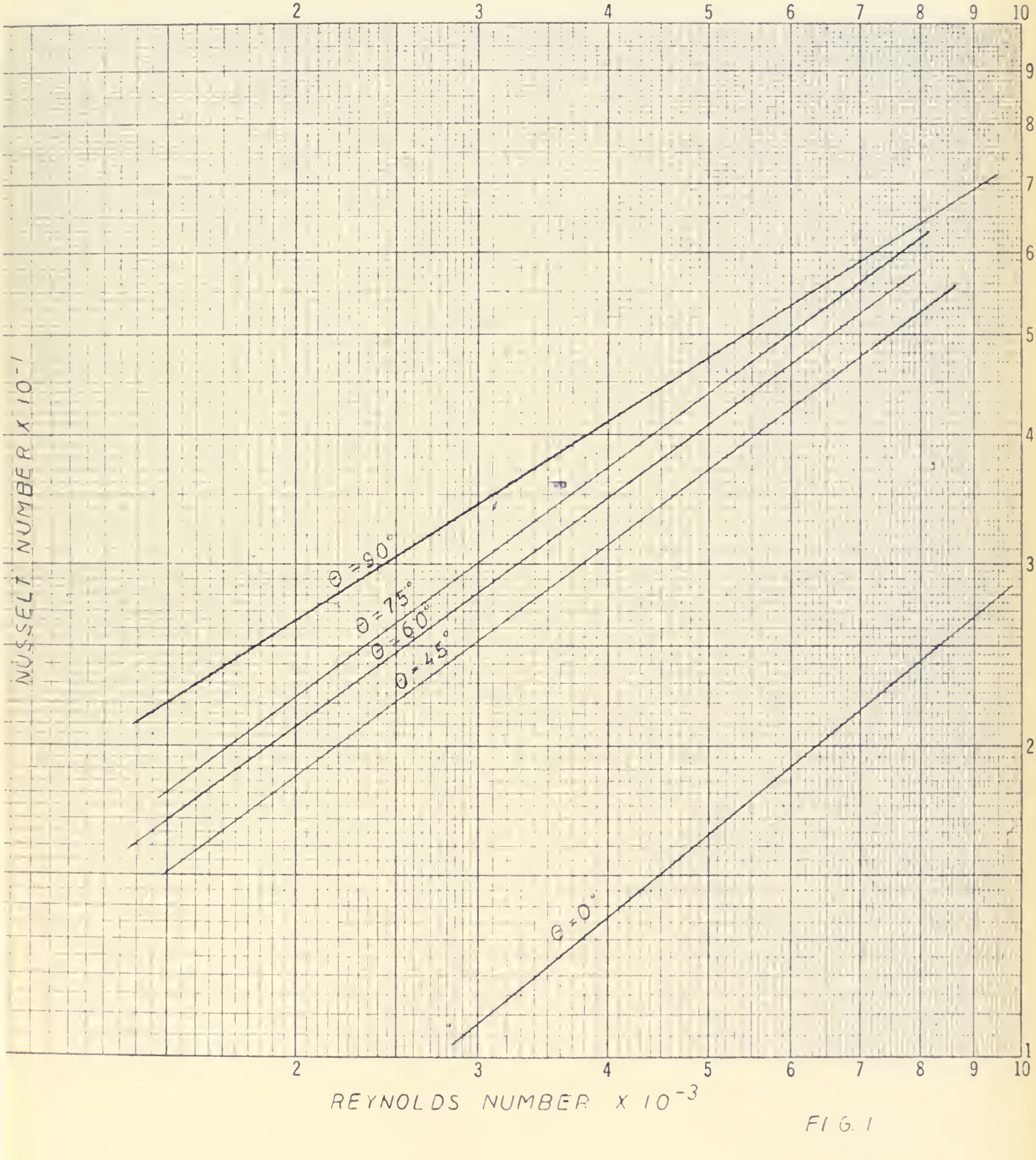


FIG. 1

COMPOSITE PLOT
VARIATION OF NUSSELT NUMBER
WITH REYNOLDS NUMBER
$S_T = S_L = 1.5 D_T$ IN-LINE

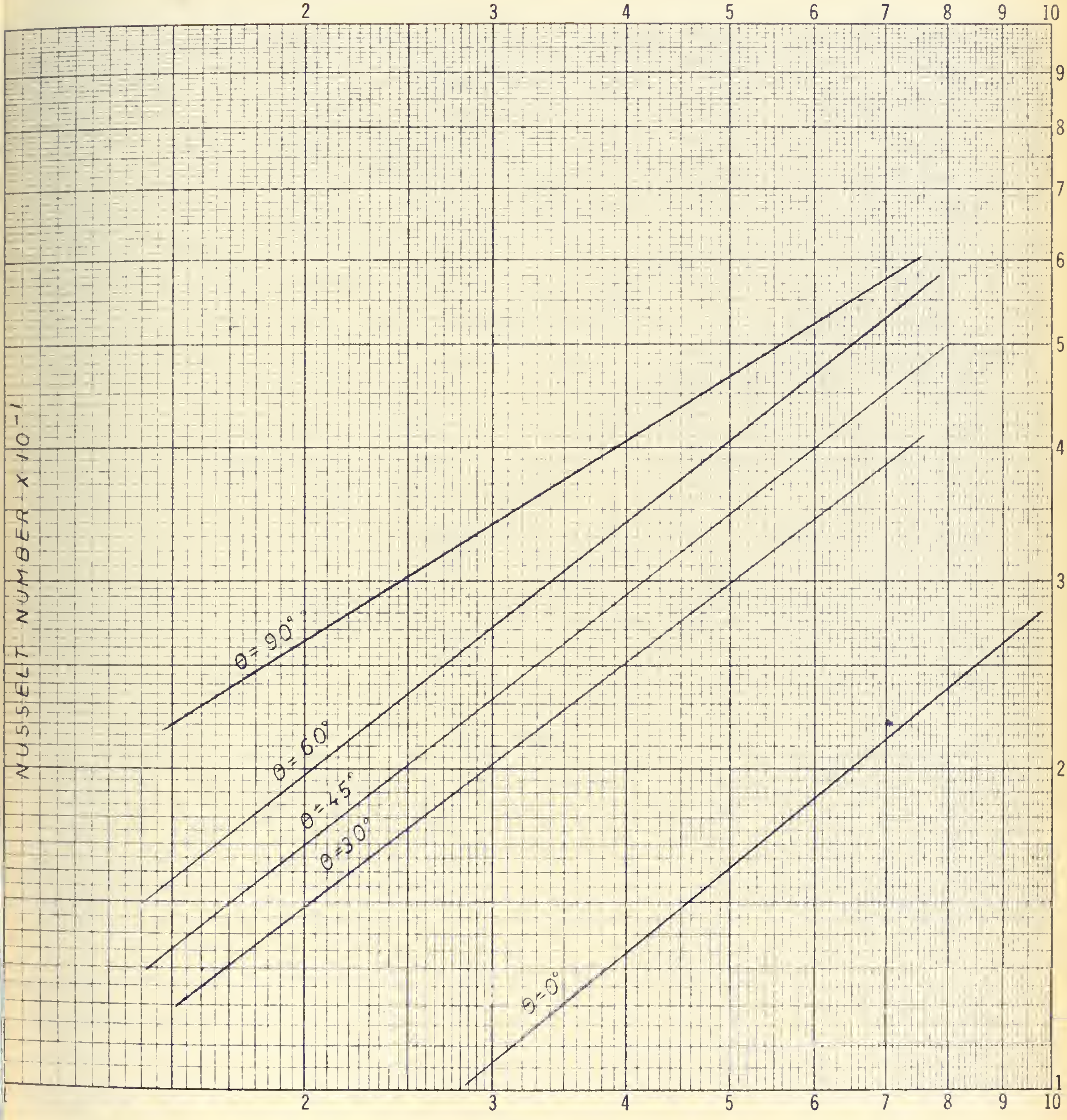


FIG. 2

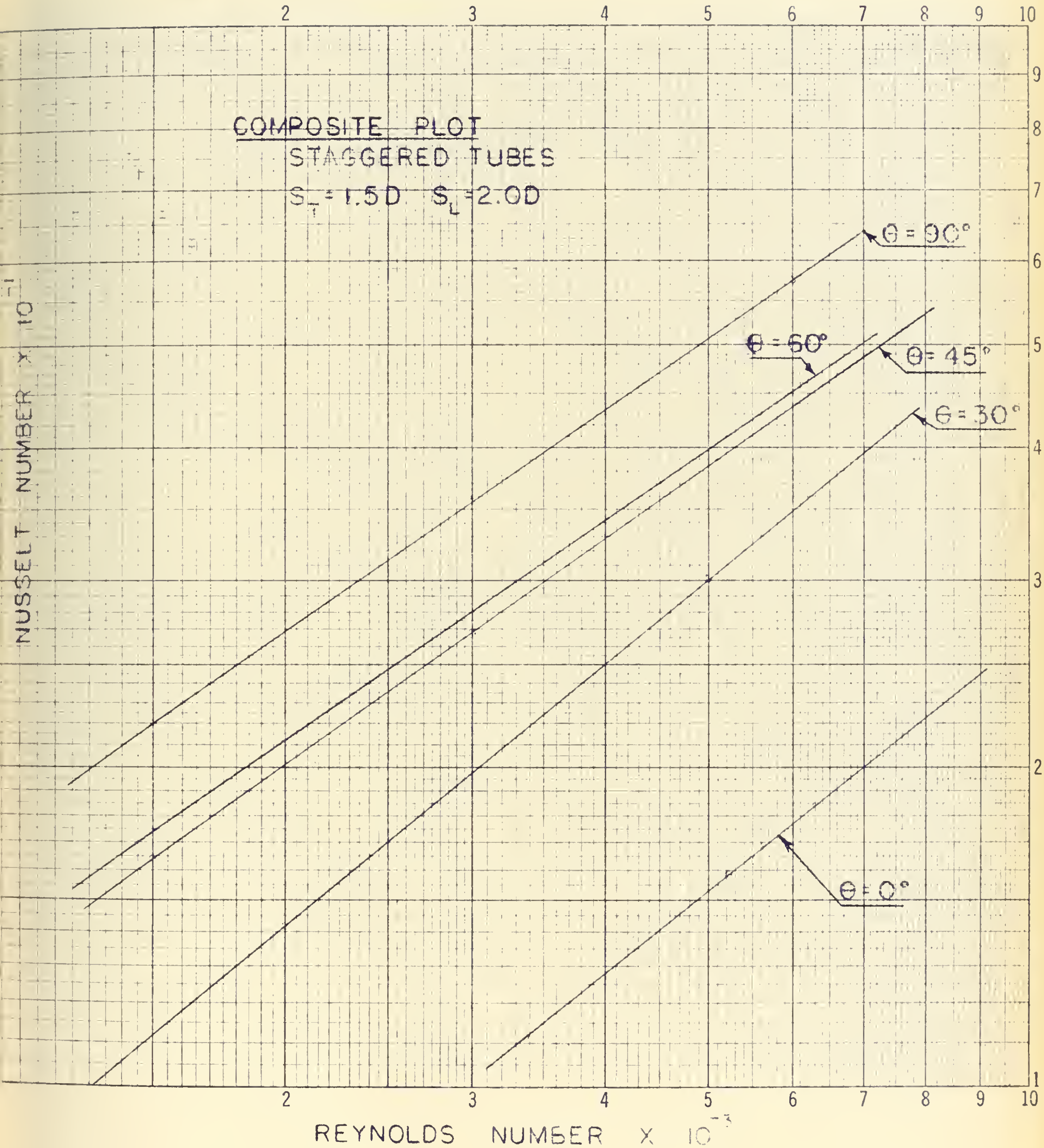

COMPOSITE PLOT
STAGGERED TUBES
$S_T = 1.5D$ $S_L = 2.0D$
θ = 90°
θ = 60°
θ = 45°
θ = 30°
θ = 0°
NUSSELT NUMBER X 10⁻¹
REYNOLDS NUMBER X 10⁻³
2
3
4
5
6
7
8
9
10
1

FIG. 3

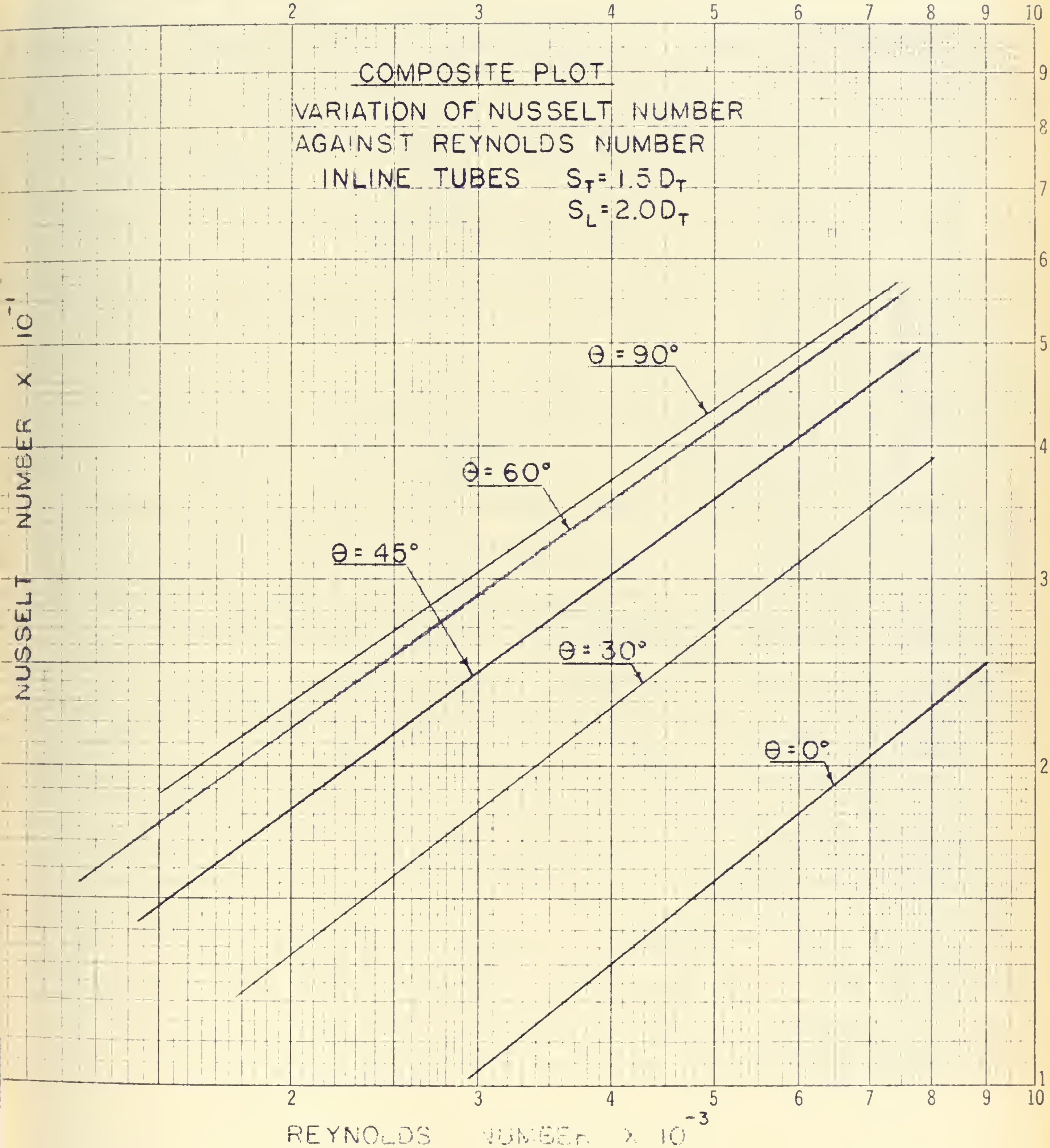

COMPOSITE PLOT
VARIATION OF NUSSELT NUMBER
AGAINST REYNOLDS NUMBER
INLINE TUBES $S_T = 1.5 D_T$
$S_L = 2.0 D_T$
θ = 90°
θ = 60°
θ = 45°
θ = 30°
θ = 0°
NUSSELT NUMBER × 10^{-1}
REYNOLDS NUMBER × 10^{-3}
2
3
4
5
6
7
8
9
10

FIG. 4

Of the three regression equations for each geometry, one represents consideration of all the points, one is determined by all the points within two standard errors, and the third represents the line determined by points within one standard error, where a standard error for a set of N points is given by the relation:

$$S.E. = \sqrt{\frac{\sum_{i=1}^{n} (Y_i - Y_{AVG})^2}{N}}$$

where Y avg. is $\sum_{i=1}^{n} \frac{Y_i}{N}$

The choice of which equation to utilize was made through inspection of the SC4020 plots of the regression equations. In almost all cases, the values of F_θ at low Reynolds Numbers were outside the two standard error criteria, and, since the first three points are among those used to make a first determination of exponent, these points influence the phase of the regression line unduly. Further, the data for values of Reynolds Number less than 2000 is suspected to be influenced by laminar flow. Thus only that data which fits within the two standard error criteria was allowed to determine the regression equation and the second set of coefficients were used for further analysis.

For design work, the equations as shown in Table I may be used if the designer is working at a specific angle of inclination and geometry. Entering with Reynolds Number as an argument, a value of F_θ will result which can be used as an additional factor in the Modified Grimison equation.

For greater convenience, two design plots have been prepared. Figures 9 and 10 in the cnclusion section, give the factor F_{θ} as it varies with angle at three constant values of Reynolds Number. There are 12 curves, three for each of the four tube arrangement geometries analyzed.

Entering with the angle of inclination and the geometry, the designer may read a value of F_{θ} for each of the two values of Reynolds Number which bracket the argument he requires. By linear interpolation, F_{θ} can be particularized to the desired Reynolds Number.

TABLE I

Summary of Inclination Factor Regression Coefficients

For Points Within Two Standard Errors

$$F_\theta = A + B\,(N_{RE})^M$$

		A	B	M
$S_T=1.5D_T$	45	0.5087726	$1.056159(10)^{-3}$	0.6510998
$S_L=1.5D_T$	60	0.6856272	$4.110530(10)^{-4}$	0.9889
STG	75	-0.6487573	0.6318375	0.1069
	90	0.8435844	$1.62334(10)^{-4}$	0.7754198
$S_T=1.5D_T$	30	0.6208538	$2.209353(10)^{-5}$	0.9889
$S_L=1.5D_T$	45	0.7091857	$3.031199(10)^{-5}$	0.9889
IN-LINE	60	0.7860375	$4.310665(10)^{-5}$	0.9889
	90	1.155682	$-4.277594(10)^{-6}$	1.00999
$S_T=1.5D_T$	30	$7.290824(10)^{-2}$	$4.853093(10)^{-2}$	0.2980699
$S_L=2.0D_T$	45	0.7260181	$3.172470(10)^{-5}$	0.9889
STG	60	0.7262158	$1.741723(10)^{-4}$	0.8012598
	90	0.7653439	$7.028655(10)^{-3}$	0.4712899
$S_T=1.5D_T$	30	0.4970187	$3.129761(10)^{-5}$	0.9889
$S_L=2.0D_T$	45	0.6867613	$2.621991(10)^{-5}$	0.9889
IN-LINE	60	0.8011853	$3.337236(10)^{-5}$	0.9889
	90	0.8751028	$2.385977(10)^{-5}$	0.9889

ANALYSIS OF FRICTIONAL RESISTANCE

Figures 51 through 66, included in Appendix H, are plots of friction factor against Reynolds Number for individual geometries and inclinations. Several points pertinent to subsequent analysis are observable from these curves. The non-linear behavior of the full logarithmic plot at low Reynolds Numbers is apparent in these plots. This behavior is a characteristic of small tube apparatuses that is consistent with the observations of previous investigators and is probably caused by laminar flow in the tube bank. In order to keep the analysis as general as possible data points with Reynolds Numbers less than 2500 have been omitted. Additionally it can be seen from Figure 55 that the data for the thirty degree angle, $S_T = S_L = 1.5D_T$, In-Line, is completely inconsistent with all the remaining data and is therefore omitted from the analysis. The inconsistenty is undoubtedly due to faulty instrumentation or operator error during the collection of this data.

The friction factor can be expressed analytically as a function of Reynolds Number by fitting the data to an equation of the form:

$$\text{FRIFAC} = \text{CONST}\ (\text{CNRE})^{\text{EXPO}}$$

using the method of least squares.

A computer program, described in Appendix H, has been utilized to compute these parameters which describe the friction factor as a function of Reynolds Number for a particular geometry and angle of inclination. The equations which include these parameters are summarized in Table II.

TABLE II

f = CONST (CNRE)^{EXPO}

	θ	CONST	EXPO
$S_T=S_L=1.5D_T$	90	1.931187	-0.457575
STAGGERED	75	0.445318	-0.045756
	60	0.045465	-0.196590
	45	0.65543	-0.043053
$S_T=S_L=1.5D_T$	90	0.261858	-0.081586
IN-LINE	60	0.037337	-0.119514
	45	0.100758	-0.024007
$S_T=1.5D_T$	90	0.431623	-0.086865
$S_L=2.0D_T$	60	0.187797	-0.028274
STAGGERED	45	0.070171	-0.089713
	30	0.040784	-0.040784
$S_T=1.5D_T$	90	0.297399	-0.055798
$S_L=2.0D_T$	60	0.074656	-0.05331
IN-LINE	45	0.017001	0.210122
	30	0.033258	0.060968

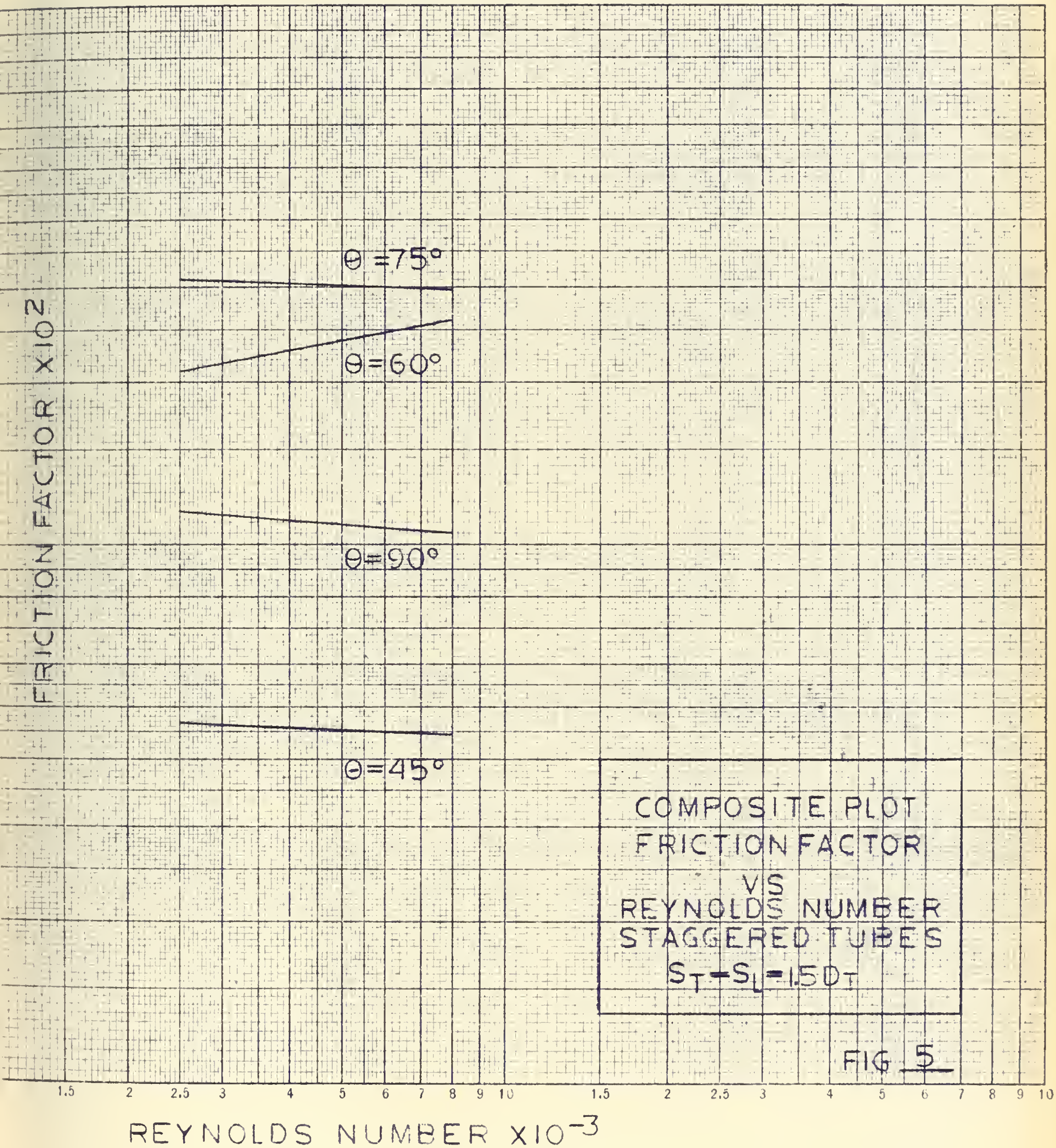
Figures 5 thru 8 are composite plots showing the variation in friction factor with Reynolds number at different flow angles for particular geometries. The plots are based on the equations listed above. From these plots it may be seen that the set for on $S_T = S_L = 1.5D_T$, STAGGERED, (Fig. 5) is not consistent with the remaining data. The data for this geometry was taken by previous investigators who experienced some difficulty in correlating it. This previous data will be omitted from further analysis.

From the equations representing the variation of friction factor with Reynolds number, it can be seen that there is no apparent pattern in the variation of either the coefficient or exponent with angle of inclination for particular geometries.

Friction factors for Reynolds Numbers of three thousand through eight thousand, in increments of one thousand, were computed as part of the analysis. Program Values of Reynolds Number = 3000, 5000 and 8000 are tabulated below to indicate the variation with flow angle for particular geometries.

REYNOLDS NUMBER = 3000

	Friction Factor				
GEOMETRY	30	45	60	75	90
$S_T = S_L = 1.5D_T$, STG	-	0.0464	0.2194	0.3087	0.1140



FRICTION FACTOR X10^2
θ =75°
θ=60°
θ=90°
θ=45°
COMPOSITE PLOT
FRICTION FACTOR
VS
REYNOLDS NUMBER
STAGGERED TUBES
S_T = S_L = 1.5 D_T
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
9
10
REYNOLDS NUMBER X10^-3

FIG 5

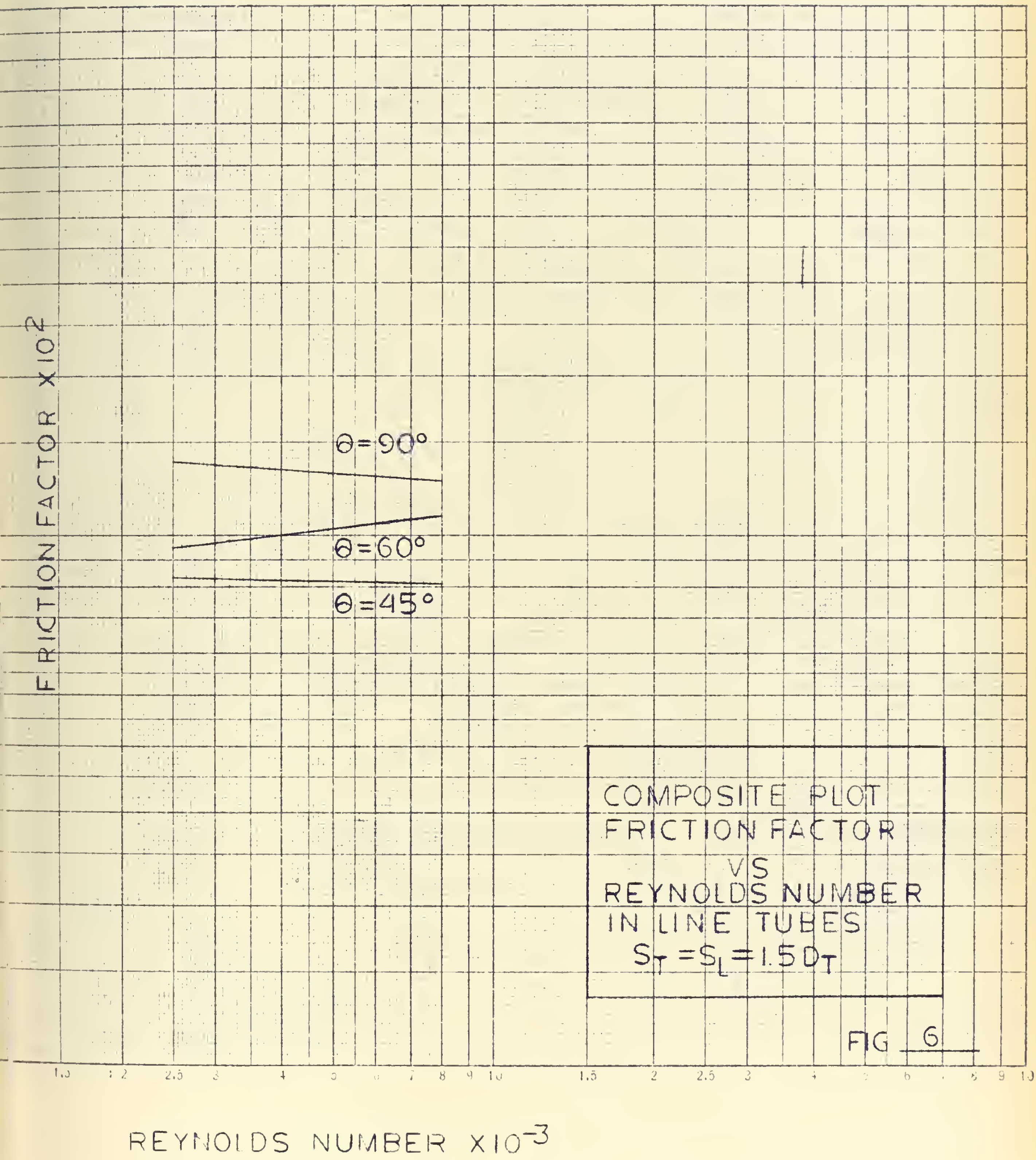

FRICTION FACTOR X10^{2}
θ=90°
θ=60°
θ=45°
COMPOSITE PLOT
FRICTION FACTOR
VS
REYNOLDS NUMBER
IN LINE TUBES
$S_T = S_L = 1.5 D_T$
1.0
2.5
3
4
5
7
8
9
10
1.5
2
2.5
3
4
6
9
10
REYNOLDS NUMBER X10^{-3}

FIG 6

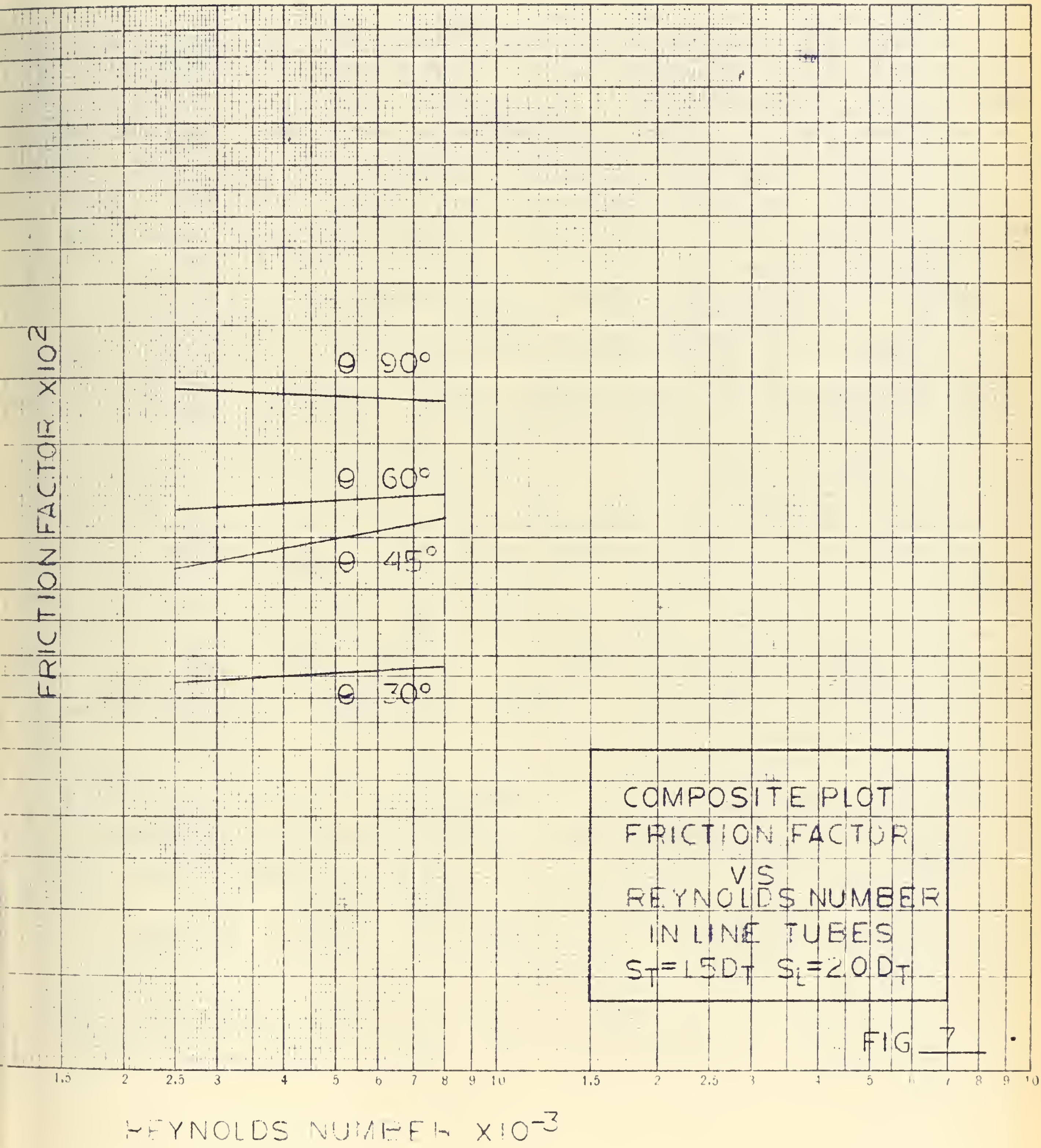
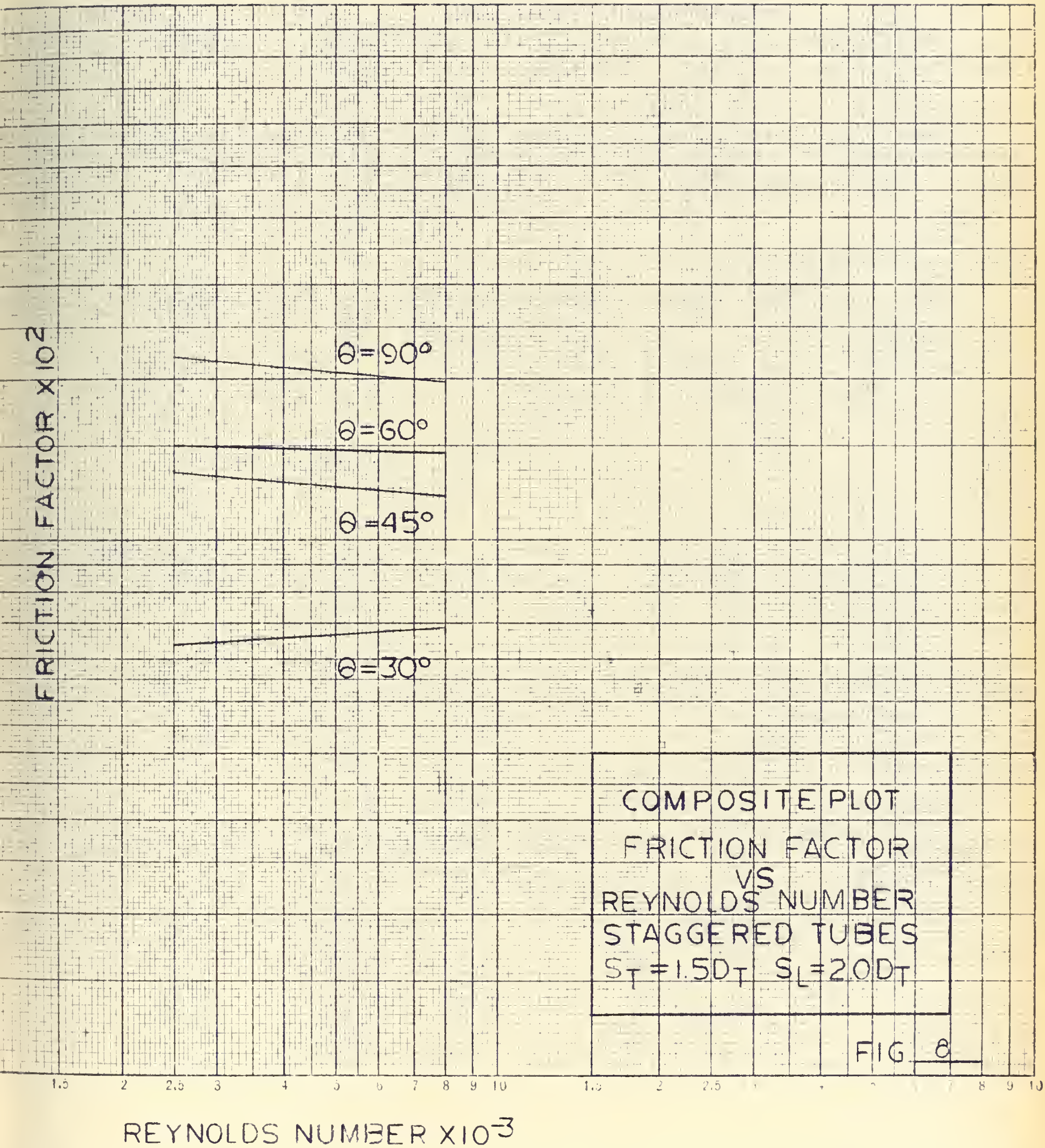

FRICTION FACTOR X10^2
θ 90°
θ 60°
θ 45°
θ 30°
COMPOSITE PLOT
FRICTION FACTOR
VS
REYNOLDS NUMBER
IN LINE TUBES
$S_T = 1.5 D_T$ $S_L = 2.0 D_T$
1.5
2
2.5
3
4
5
6
7
8
9
10
REYNOLDS NUMBER X10^-3

FIG 7 .



COMPOSITE PLOT
FRICTION FACTOR
VS
REYNOLDS NUMBER
STAGGERED TUBES
$S_T = 1.5 D_T$ $S_L = 2.0 D_T$

FIG. 8

REYNOLDS NUMBER = 3000 continued

GEOMETRY	Friction Factor 30	45	60	75	90
$S_T=S_L=2.0D_T$, I.L.	-	0.0831	0.0972	-	0.1363
$S_T=1.5D_T$, $S_L=2.0D_T$, STG	0.0648	0.1312	0.1498	-	0.2153
$S_T=1.5D_T$, $S_L=2.0D_T$, I.L.	0.0542	0.0914	0.1144	-	0.1902
REYNOLDS NUMBER = 5000					
$S_T=S_L=1.5D_T$, STG	-	0.0454	0.2426	0.3016	0.1095
$S_T=S_L=1.5D_T$, I.L.	-	0.0821	0.1033	-	0.1307
$S_T=1.5D_T$, $S_L=2.0D_T$ STG	0.0668	0.1258	0.1476	-	0.2060
$S_T=1.5D_T$, $S_L=2.0D_T$ I.L.	0.0599	0.1018	0.1176	-	0.1850
REYNOLDS NUMBER = 8000					
$S_T=S_L=1.5D_T$ STG	-	0.0445	0.2661	0.2952	0.1054
$S_T=S_L=1.5D_T$ I.L.	-	0.0812	0.1093	-	0.1258
$S_T=1.5D_T$, $S_L=2.0D_T$ STG	0.0686	0.1206	0.1457	-	0.1977
$S_T=1.5D_T$, $S_L=2.0D_T$ I.L.	0.0575	0.1124	0.1206	-	0.1801

From these values, a relationship can be developed which expresses friction factor at any angle as a function of the friction factor at ninety degrees by simply taking ratios of the values and plotting them: i.e.

$$F\theta = \frac{f\theta}{f90}$$

where $f\theta$ = the friction factor at any angle,

$f90$ = the friction factor at ninety degrees as expressed by f, = CONST $(\text{CNRE})^{\text{EXPO}}$ CONST and EXPO being particularized to the geometry.

The values so derived are tabulated below:

$N_{RE} = 3000$	$F\theta$			
GEOMETRY	30	45	60	90
$S_T = S_L = 1.5D_T$ I.L.	-	0.6097	0.7131	1.000
$S_T = 1.5D_T$ $S_L = 2.0D_T$ STG	0.3010	0.6093	0.6958	1.000
$S_T = 1.5D_T$ $S_L = 2.0D_T$ I.L.	0.3500	0.4805	0.6015	1.000
$N_{RE} = 5000$				
$S_T = S_L = 1.5D_T$ I.L.	-	0.6282	0.7904	1.000
$S_T = 1.5D_T$ $S_L = 2.0D_T$ STG	0.3243	0.6107	0.7165	1.000
$S_T = 1.5D_T$ $S_L = 2.0D_T$ I.L.	0.3388	0.5502	0.6356	1.000
$N_{RE} = 8000$				
$S_T = S_L = 1.5D_T$ I.L.	-	0.6455	0.8688	1.000
$S_T = 1.5D_T$ $S_L = 2.0D_T$ STG	0.3470	0.6100	0.7370	1.000
$S_T = 1.5D_T$ $S_L = 2.0D_T$ I.L.	0.3182	0.6241	0.6696	1.000

Values of the ratio $F\theta$ are plotted and are included in the Conclusion section as Figures 11 through 13. By entering the applicable curve with values of flow angle the ratio of friction factor at the angle θ to that at ninety degrees may be obtained. For values of Reynolds Numbers other than those tabulated, linear interpolation may be used.

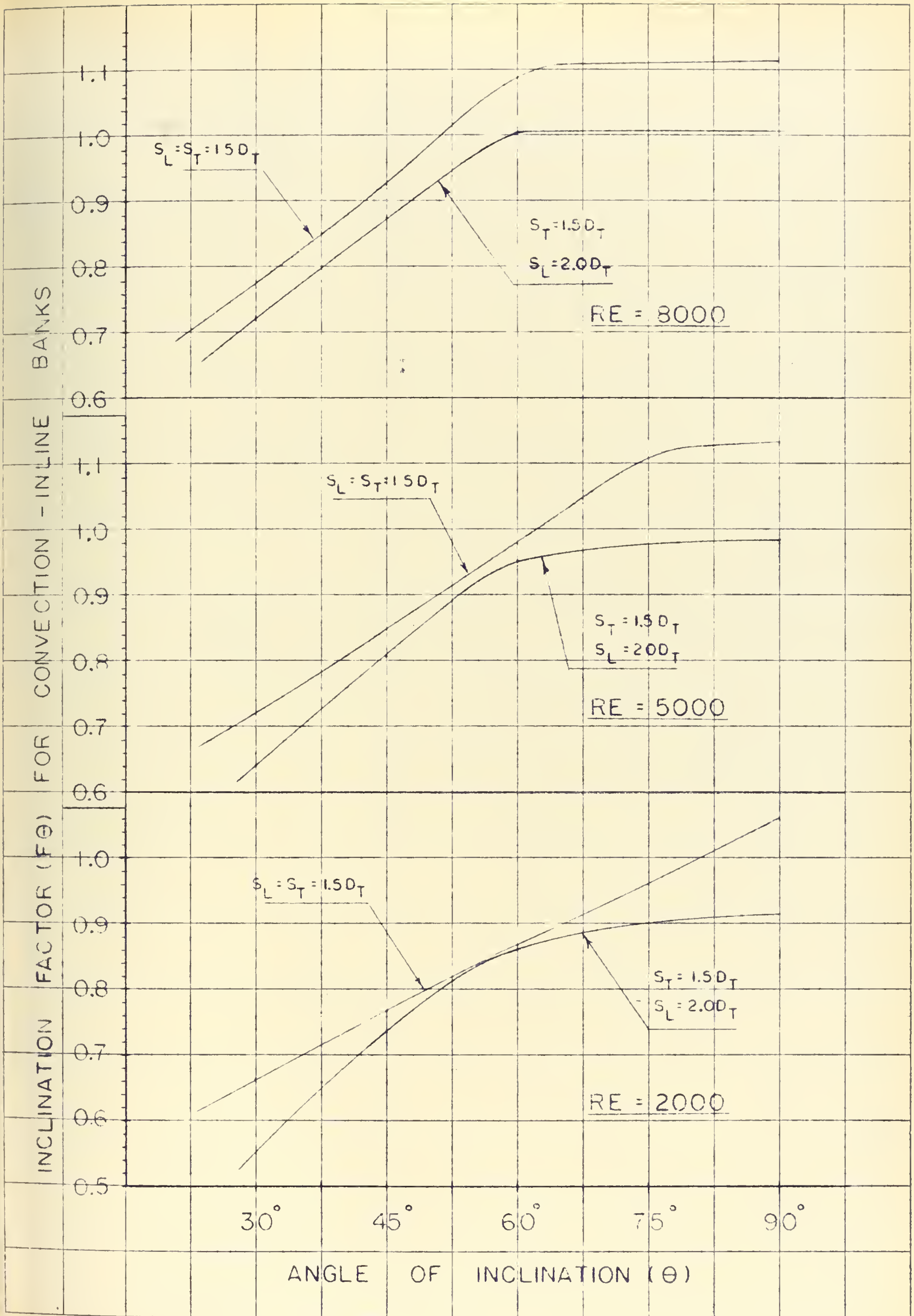
CONCLUSION

Convection Heat Transfer

Figures 9 and 10 represent the plotted results of the equations developed by the regression analysis of individual inclination factors. These plots show the variation of inclination factor with angle for in-line and staggered geometries. Six curves are plotted in each case representing constant values for Reynolds Number of 2000, 5000 and 8000 and particular values of transverse and longitudinal tube pitch. The curves can be used directly as a design aid by applying the value of inclination factor obtained as a multiplier to the modified Grimison equation. Values of the inclination factor for Reynolds Numbers other than those plotted may be obtained by linear interpolation. The modified Grimison equation now becomes:

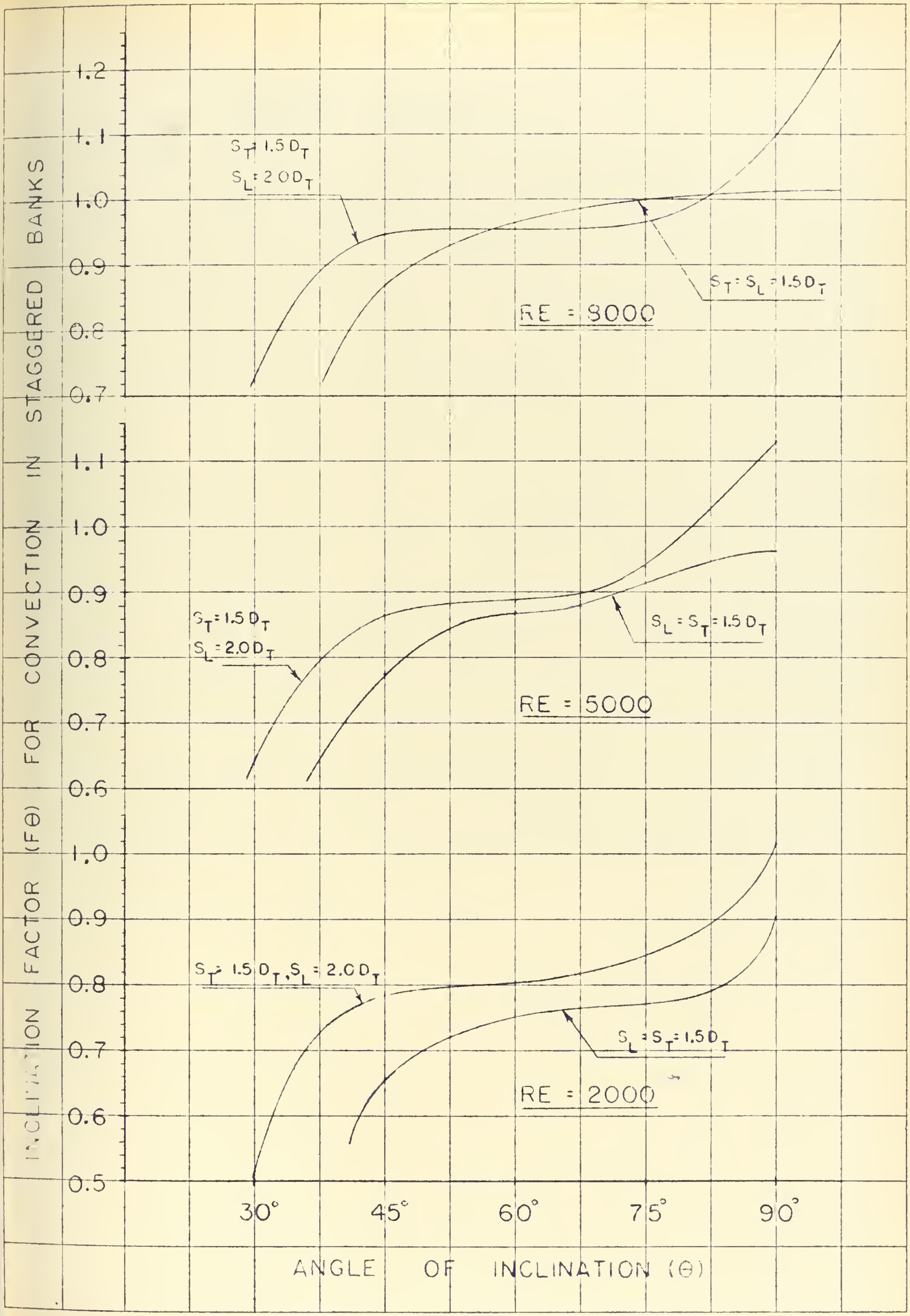
$$\frac{h_f D_t}{K} = 0.292\ F_D F_A F_\theta\ f_D\ f_T \left(N_{RE}\right)^{0.60} \left(P_r\right)^{1/3}$$

It should be noted that the variation of inclination factor with angle of inclination is by no means linear so that there are regions for both staggered and in-line geometries in which relatively large changes in angle of inclination cause small changes in the rate of heat transfer. The reverse situation also can be obtained. The choice of which region is optimum must be left to the user who is familiar with the requirements and limitations of his particular job.



1.1
1.0
0.9
0.8
0.7
0.6
$S_L = S_T = 1.5 D_T$
$S_T = 1.5 D_T$
$S_L = 2.0 D_T$
RE = 8000
1.1
1.0
0.9
0.8
0.7
0.6
$S_L = S_T = 1.5 D_T$
$S_T = 1.5 D_T$
$S_L = 2.0 D_T$
RE = 5000
1.0
0.9
0.8
0.7
0.6
0.5
$S_L = S_T = 1.5 D_T$
$S_T = 1.5 D_T$
$S_L = 2.0 D_T$
RE = 2000
30°
45°
60°
75°
90°
ANGLE OF INCLINATION (Θ)
INCLINATION FACTOR (FΘ) FOR CONVECTION - INLINE BANKS

FIG. 9



INCLINATION FACTOR (Fθ) FOR CONVECTION IN STAGGERED BANKS
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
$S_T = 1.5 D_T$
$S_L = 2.0 D_T$
$S_T = S_L = 1.5 D_T$
RE = 8000
$S_L = S_T = 1.5 D_T$
RE = 5000
$S_T = 1.5 D_T, S_L = 2.0 D_T$
RE = 2000
30°
45°
60°
75°
90°
ANGLE OF INCLINATION (θ)

FIG. 10

FRICTIONAL RESISTANCE

Figures 11 through 13 represent the plotted results of the analysis of frictional resistance for each of the three geometries for which reliable data was obtained. Each figure contains three curves, one each for values of Reynolds Numbers of 3000, 5000 and 8000. Additionally on each figure there appears an equation in the form:

$$f = C\left(F_{\theta}\right)\left(N_{RE}\right)^{X}$$

This is the equation for the friction factor in each case.

Two uses of the curve are suggested. The first is to calculate an absolute value of friction factor. This method should be used with caution for while the method of obtaining, reducing and analyzing frictional resistance data is believed to be more accurate that that used by previous investigators it does not agree closely with their work. The second use is to estimate qualitatively the effect of varying the flow angle on the frictional resistance in a particular piece of heat transfer equipment.

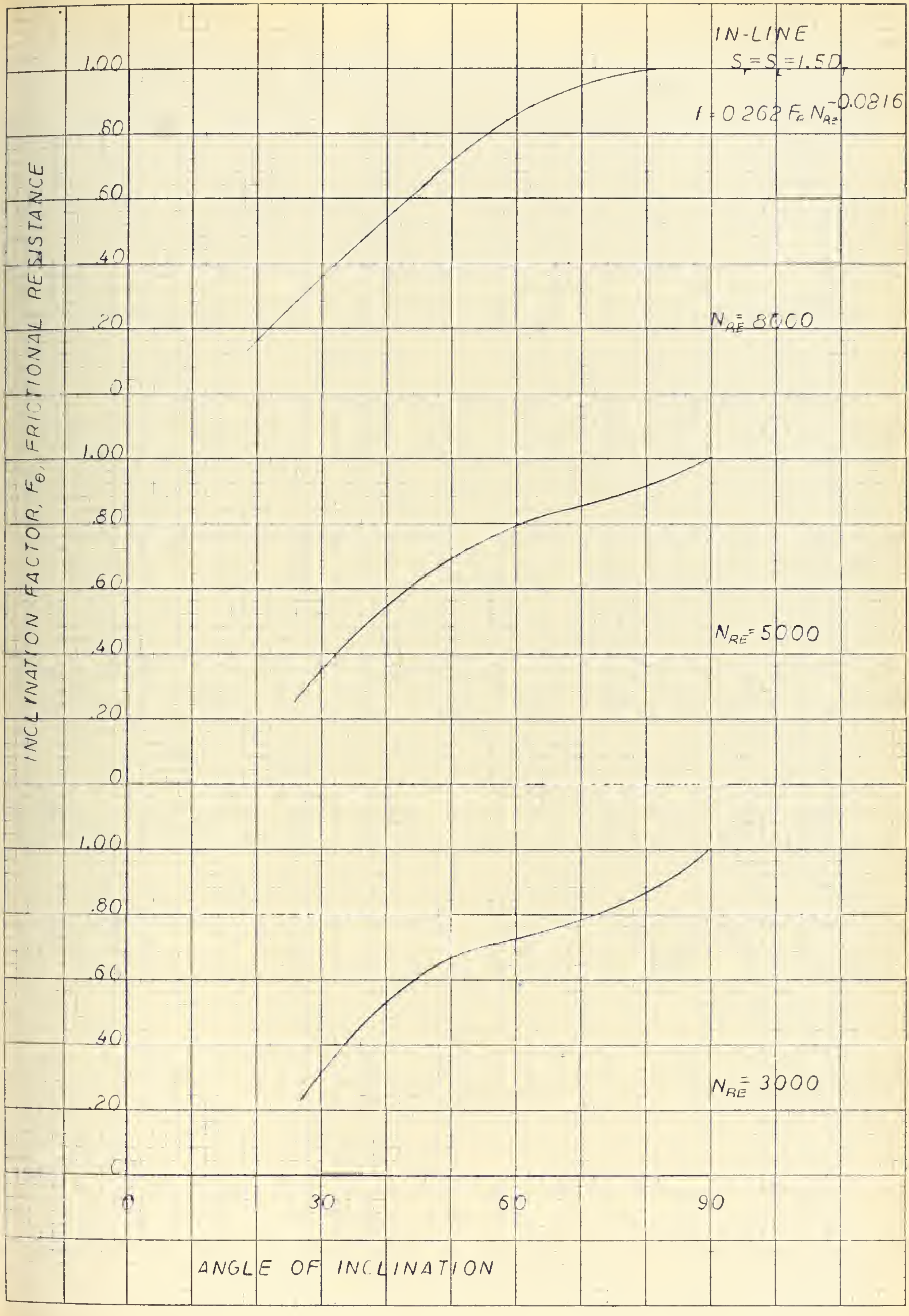

IN-LINE
$S_T = S_L = 1.5 D_T$
$f = 0.262 F_\theta N_{RE}^{-0.0816}$
INCLINATION FACTOR, F_θ, FRICTIONAL RESISTANCE
1.00
.80
.60
.40
.20
0
$N_{RE} = 8000$
$N_{RE} = 5000$
$N_{RE} = 3000$
0
30
60
90
ANGLE OF INCLINATION

FIG. 11

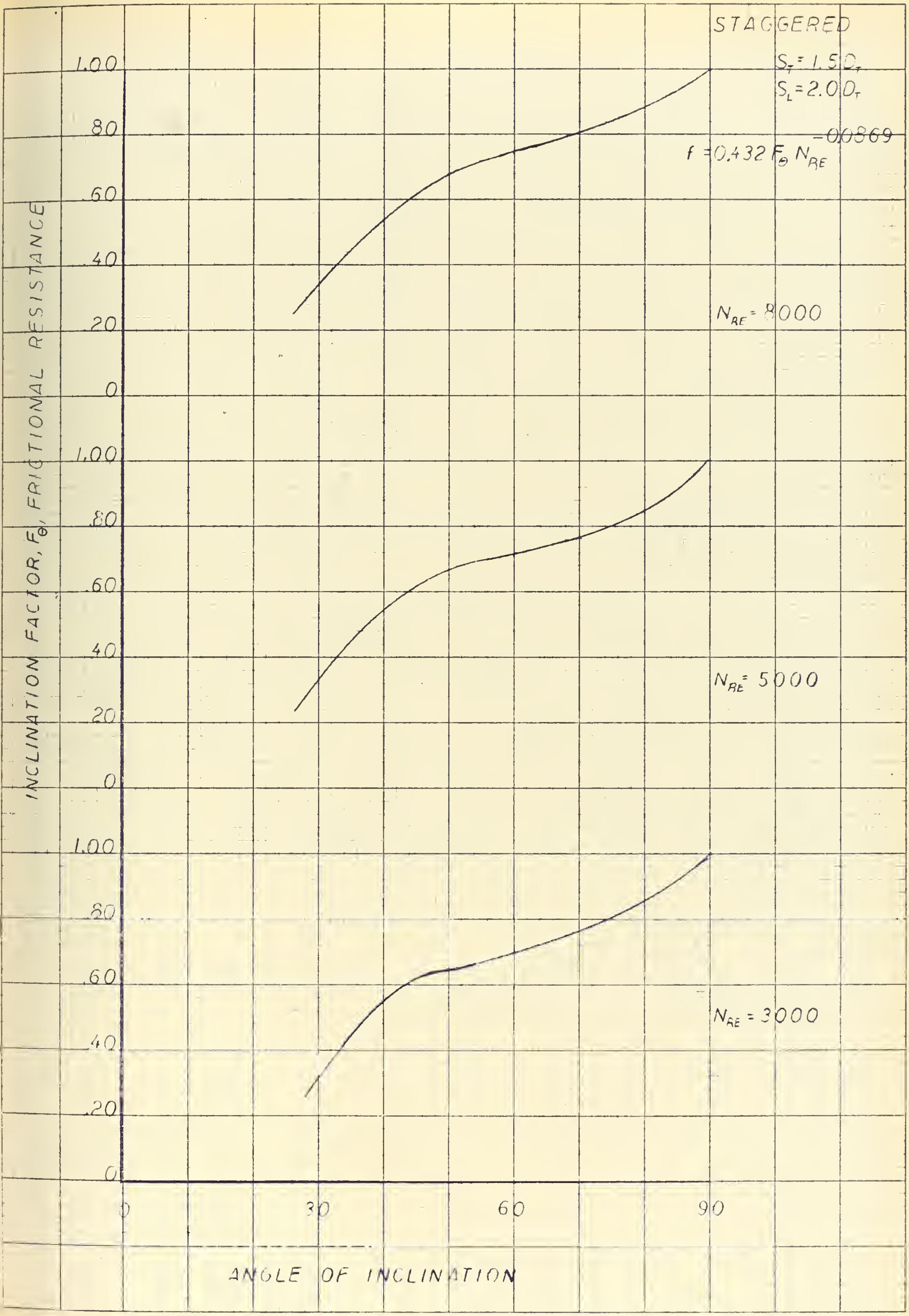

STAGGERED
$S_T = 1.5 D_T$
$S_L = 2.0 D_T$
$f = 0.432 F_\theta N_{RE}^{-.00869}$
$N_{RE} = 8000$
$N_{RE} = 5000$
$N_{RE} = 3000$
INCLINATION FACTOR, F_θ, FRICTIONAL RESISTANCE
1.00
.80
.60
.40
.20
0
0
30
60
90
ANGLE OF INCLINATION

FIG. 12

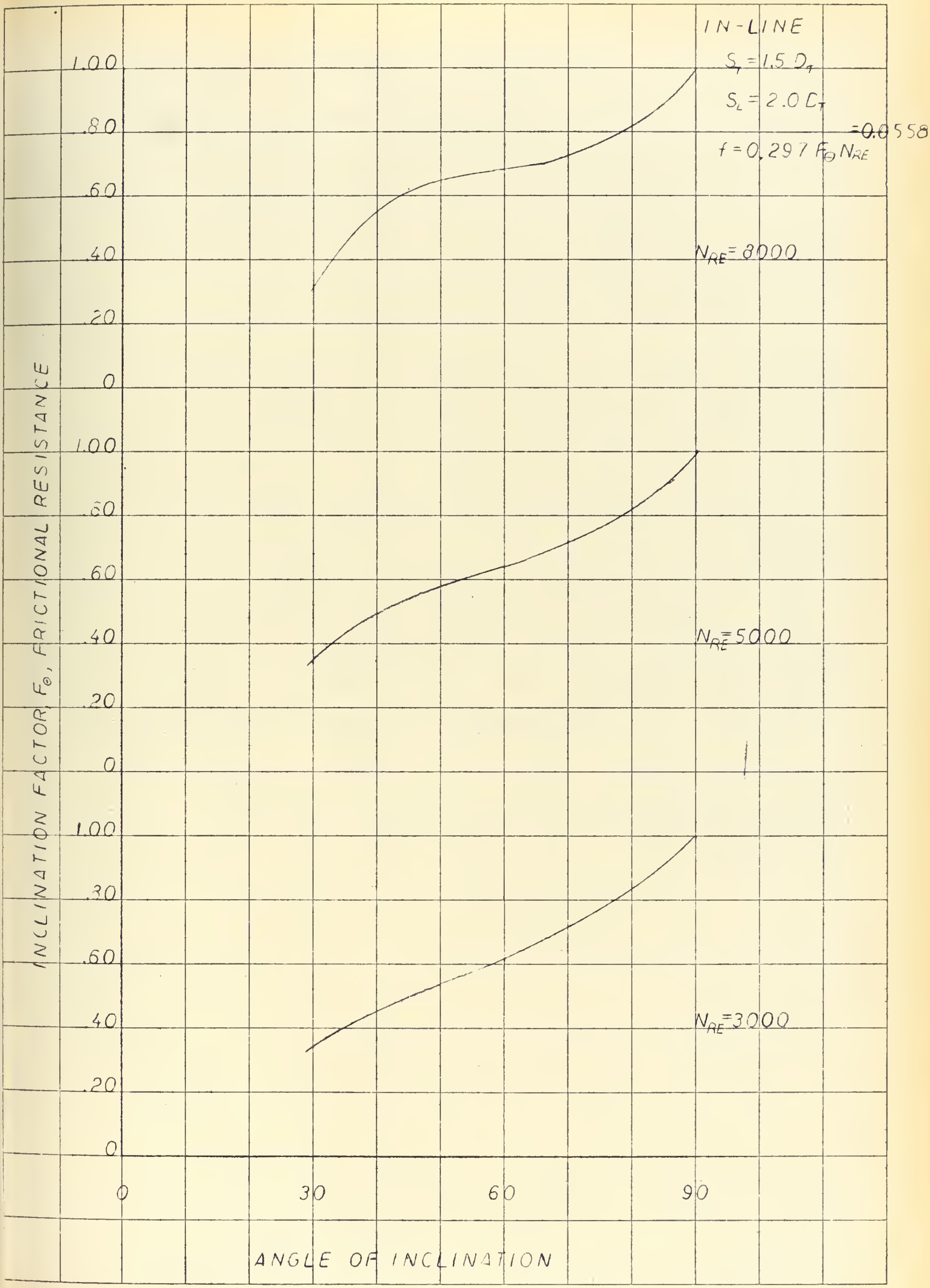

IN-LINE
$S_T = 1.5\ D_T$
$S_L = 2.0\ D_T$
$f = 0.297\ F_\Theta\ N_{RE}^{-0.0558}$
$N_{RE} = 8000$
$N_{RE} = 5000$
$N_{RE} = 3000$
1.00
.80
.60
.40
.20
0
0
30
60
90
INCLINATION FACTOR, F_Θ, FRICTIONAL RESISTANCE
ANGLE OF INCLINATION

FIG. 13

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

The apparatus, test procedure and method of reducing and analyzing data in this thesis represent a suitable method of empirically determining the effect of flow angle on convection heat transfer and frictional resistance in a tube bank. The results presented are limited in that they include only four possible tube geometries.

It is recommended that the series be extended to include all values of transverse and longitudinal tube pitches likely to be found in modern heat exchangers. Such work would involve manufacture of new tube banks and sealing strips. It is further recommended that data be taken at an angle of seventy-five degrees both for other geometries which may be tested and for those for which this angle has not been previously used. The additional point would be of great assistance in firmly locating the upper end of the inclination factor curves.

If a blower of larger capacity should become available the test data for all geometries should be extended to higher Reynolds numbers. Prospective investigators are advised that the limit of the currently installed pressure instrumentation has been reached by the present air supply system. They are also advised that the manufacturing processes are long and tedious and that the condition of the laboratory steam plant should be carefully investigated before undertaking to use it.

The reduction and analysis of test data could be facilitated by combining the three computer programs used in this work into one program to reduce and analyze data in one computation.

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APPENDIX A

Apparatus

At the onset of the project, it was felt that the apparatus as designed by Bond and Wallin and later used by Kiss and Smith would not be adaquate for the task without considerable modification. The apparatus as constructed and available had been used for one basic geometry by Kiss and Smith and had an inherent disadvantage in that it was difficult to make any alteration in tube geometry.

The design of a new test section was therefore undertaken. The principles which guided the design are:

1. The section must be of the same cross sectional dimensions as the original apparatus as verified by Bond and Wallin.

2. The section must have the capability of rapid tube geometry changes.

3. All manufacturing operations necessary for completion of the design must be feasible with equipment available in the Webb shop facility.

4. The design must utilize the same tube banks that were prepared for the previous investigators.

A design which satisfied the four stated requirements was developed. The configuration is generally the same as that used in the earlier experiments. The steam supply and drain line were used without modification, as was the air supply

system including the orifice meter. The entire test section was rebuilt in accordance with the plan shown as Fig. 15 in this appendix.

The test section consists of two rectangular wooden boxes, closed at one end, which serve as the entrance and exhaust portions of the test unit. Connecting these two end pieces to form a continuous square duct, is a center section of aluminum alloy. This center section is designed with stationary side plates and movable top and bottom plates. These features enables the tube bank to be adjusted to any angle from vertical through 60 degrees from the vertical. This was the practical extent of adjustment in that the tube banks were not long enough between headers to permit another range. This is, however, considered to be a sufficiently wide range, as it permits angles of flow incidence from 30 degrees to 90 degrees, at any practical increment. This design parameter sized the length of the aluminum center section at 30 inches.

The end sections are made up of 3/4 inch exterior grade marine plywood. The joints are made up with glue and joined with #8 x 1¼ " wood screws. The sides of the section are routed 3/16" by 3" to receive the sides of the aluminum center section such that the center plate will fit flush. The wooden sides are also routed at the top and bottom edge, 3/16" wide by ¼" deep to receive the edges of the sliding top plates. The top and bottom of the wooden intake and exhaust sections

are routed to a depth of 3/16 inch to effect a flush fit for the sliding plates of the aluminum center section. They are also routed across the width and to a length which will accommodate the sliding plates through the range of inclination of the tube bank. This range is shown in Figure 17, the drawing of the section. The intake section as a 6 inch 90° elbow secured to the end for delivery of air through a 6" diameter hole. The exhaust section has a similar stove pipe elbow made up to the side of the section. The heated air exhausts through a 6 inch diameter hole in the box then through the stove pipe exhaust line to the atmosphere.

Both intake and exhaust sections were sanded smooth and finished with two coats of shellac prior to assembly. After assembly, all edges were caulked with a silicone rubber sealant and the stove pipe connections were made up with asbestos cloth gasketing using Permatex compound for a leakproof joint.

The center portion of the test section is fabricated from 2024-T3 aluminum alloy. This alloy was chosen for its free machining characteristics, since several machining operations were required in manufacturing the numerous sealing strips between the tube banks. It was later learned that the temper of this plate was not correct in that when the plates were cut to size and the edges and sliding grooves milled, the plates warped out of plane due to locked in rolling stresses. After several unsuccessful attempts to straighten the plates by different methods, the decision was made to anneal the plates

the plates and thus stress relieve them. Several industrial contacts were made, and through the courtesy and kindness of the Sylvania-Corning plant in Hicksville, N.Y., the plates were annealed. Provided thus with plane surfaces, construction of the center section may proceed. One further note could be added for the benefit of those who may be curious, a more proper alloy choice for this application is 2024-T53 this temper being stress relieved by stretching. The side plates were made up with all edges milled and fastened to the wooden end pieces by flat heat wood screws, countersunk to effect a plane surface. The top movable plates were made up having all edges milled and two 3/16" wide by 1/16 inch deep groove milled in the sides to effect a seal with the side plates and to provide a channel for guidance of the moving plates. Each top and bottom plate (four total) has a projection along each edge which slides in a channel.

The channel was made from an aluminum storm window shape and proved to have insufficient strength to hold the weight of the tube bank and secure the plates in position as well. To correct this, heavy steel yokes were made from angle and threaded to close the section and secure the sealing strips in place. All but one of the channels were removed, the one remaining only to serve as a positioning device. Manufacture of the sealing strips represented the largest expenditure of time for any one operation. For each of the 12 combinations of angle and geometry, 22 sealing strips were required, 11 each for top and bottom. Each sealing strip required edge

milling, groove milling, and 22 holes drilled or milled to close tolerances for completion. In all, 5680 holes were machined, and a total of 264 strips were prepared. The sealing strips proved very satisfactory in maintaining the tube geometry while providing excellent sealing characteristics. The only modification required was to provide a small hole in the end of each strip to permit the separate pieces to be wired to hold them in place while changing tube geometry. An isometric sketch showing the arrangement of the center test section and the sealing strips is provided as Figure 15. Drawings showing the sealing strip as a part of the test section and in detail appear as Figures 17 and 18. A photograph of the sealing strips in detail is available as Figure 22.

The section is supported from a laboratory table by two wooden frames and a framework of steel angle which was modified only to facilitate the changing of the geometry. This modification consisted of welding an angle on each corner of the metal structure to provide support for the tube bank headers when changing the sealing strips.

The tube bank is that used by previous investigators. It is made up of 10 rows of ¼ inch O.D. copper tubes, 22 tubes per row, with each row of tubes being fitted with an inlet and exhaust header of 1½ inch copper pipe. A detail drawing of an individual tube bank is shown in Figure 16. The inlet headers are connected to the steam supply moisture trap by 3/8 inch copper tubing. Many of these lengths of tubing had

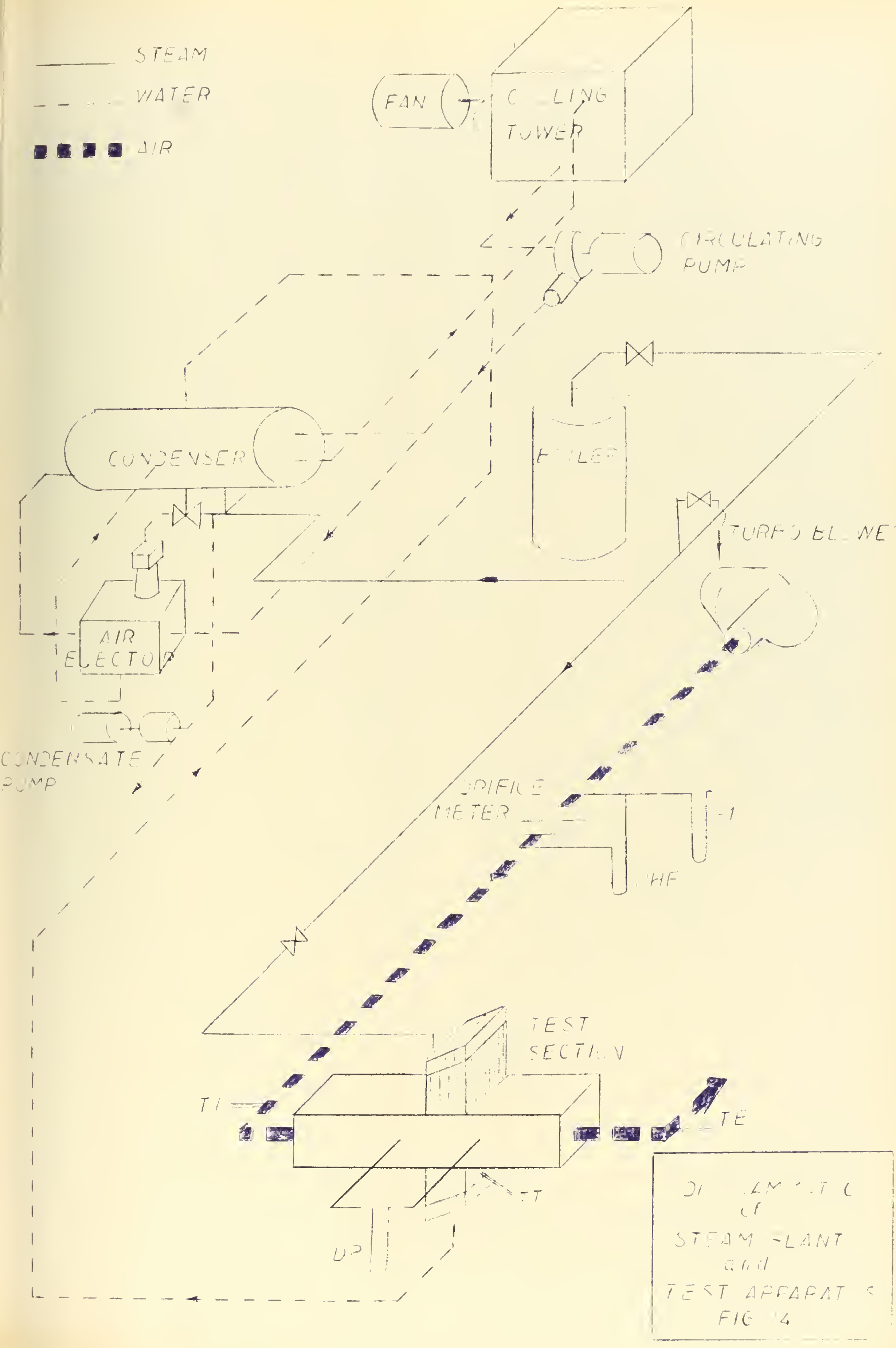
had to be replaced to permit the freedom of movement required in the tube bank. The exhaust headers were connected in the same manner to a drain header of 1½ inch copper pipe. An additional problem was that these lines kinked when moved about due to strain hardening and several were replaced for this reason. For some geometry changes, the exhaust and supply lines were completely disconnected to avoid this problem.

Two small holes are provided in one side of the center test section for thermistor leads. Four holes are provided for pressure taps in the test section. Two are in the inlet section, positioned in the middle of the vertical height and 4 inches from the center section. Two taps are provided in the exhaust section on a similar vertical position, 4 inches from the test section. Thermistor probes are provided in the 6 inch inlet piping just before the entrance elbow and in the 6 inch outlet section to avoid radiation effects from the tube bank.

Previous investigators had used various methods of sealing the banks; References 4 and 8. The method used in this series of tests, though long and painstaking in preparation, proved worth the effort while testing. There was no need to use any sealing compound once the tubes were in place and the top and bottom moving plates made tight. The tolerance to which the sealing strip holes were prepared was 0.008 inch and there was little or no leakage. Further, a geometry change could be made in about two hours on the average and there was no glue,

sealer, etc. to clean from the tube to cause further delay. In this regard, the extra effort was rewarded and this arrangement is recommended for later investigators.

Figure 14 shows an overall isometric view of the steam plant and test apparatus.



DIAGRAMMATIC
of
STEAM PLANT
and
TEST APPARATUS
FIG 14

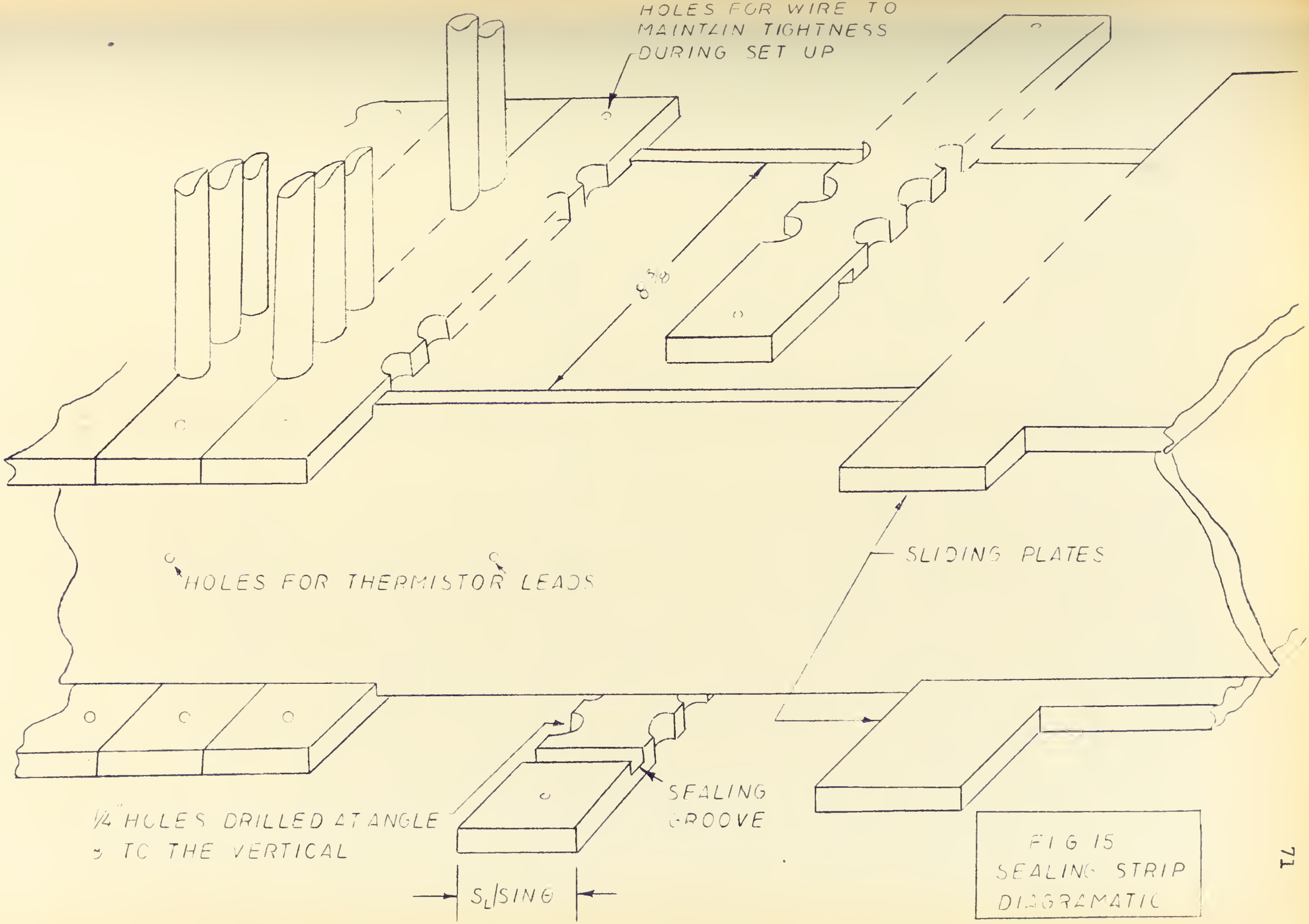


FIG 15
SEALING STRIP
DIAGRAMATIC

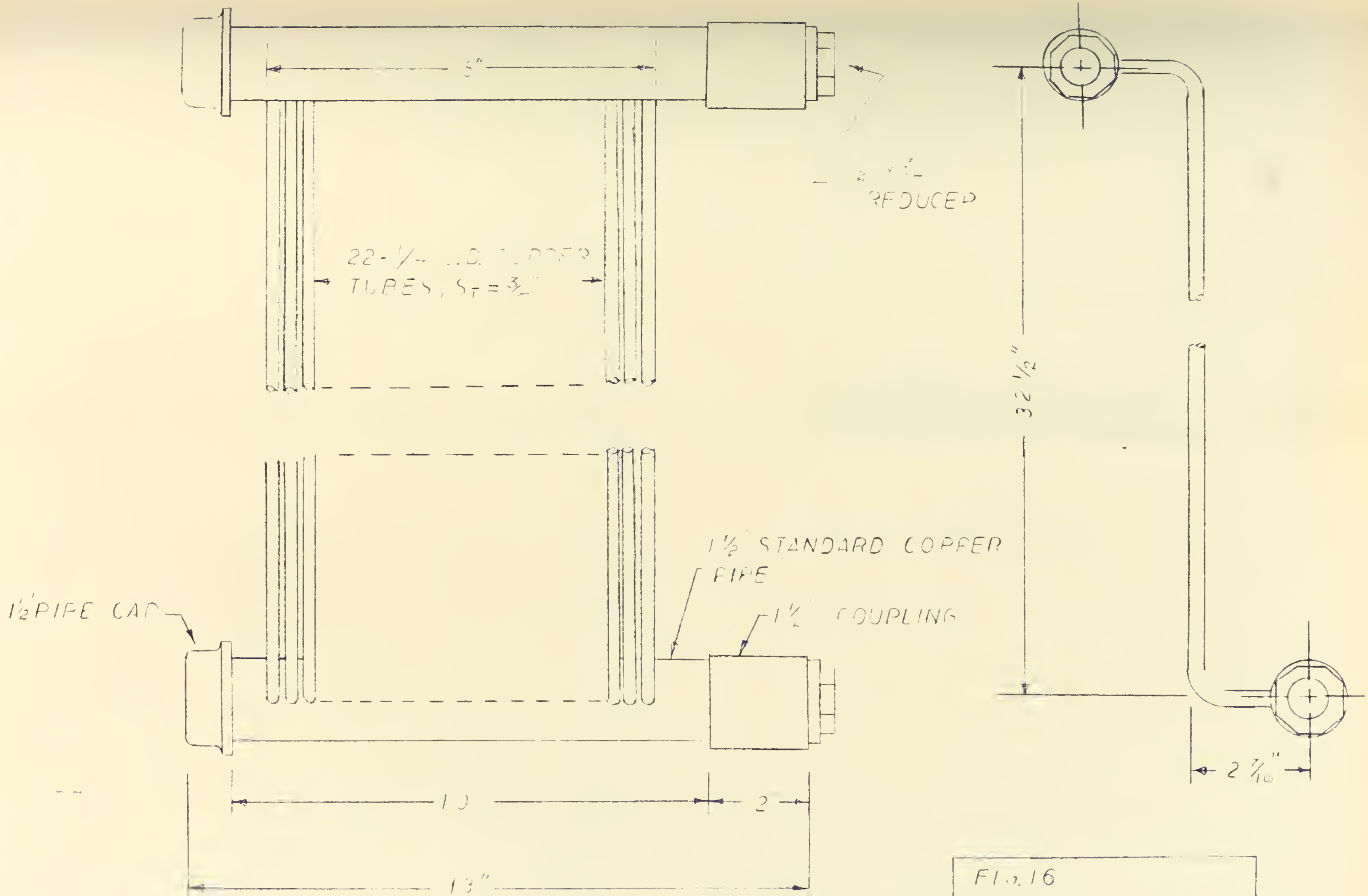
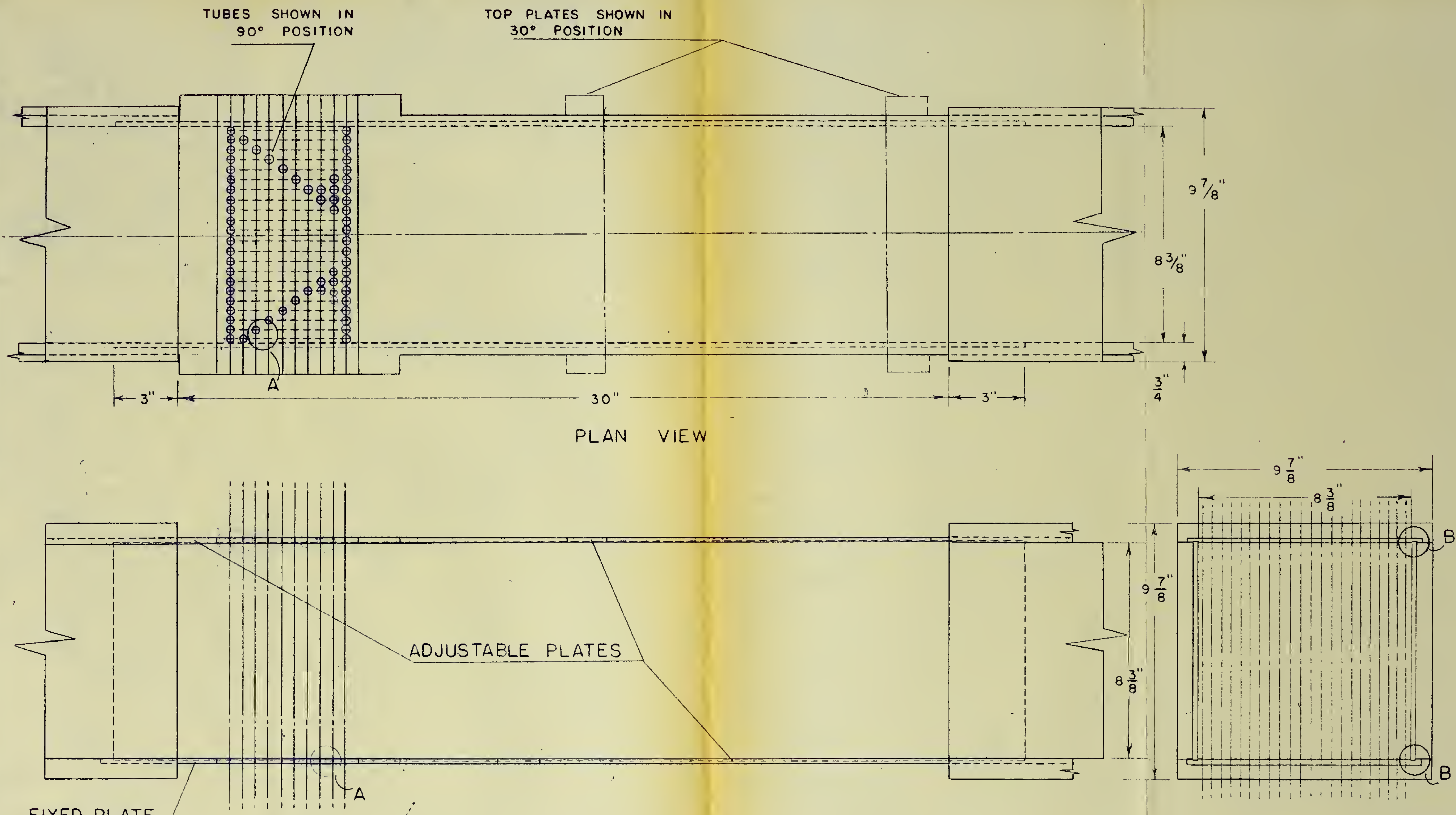
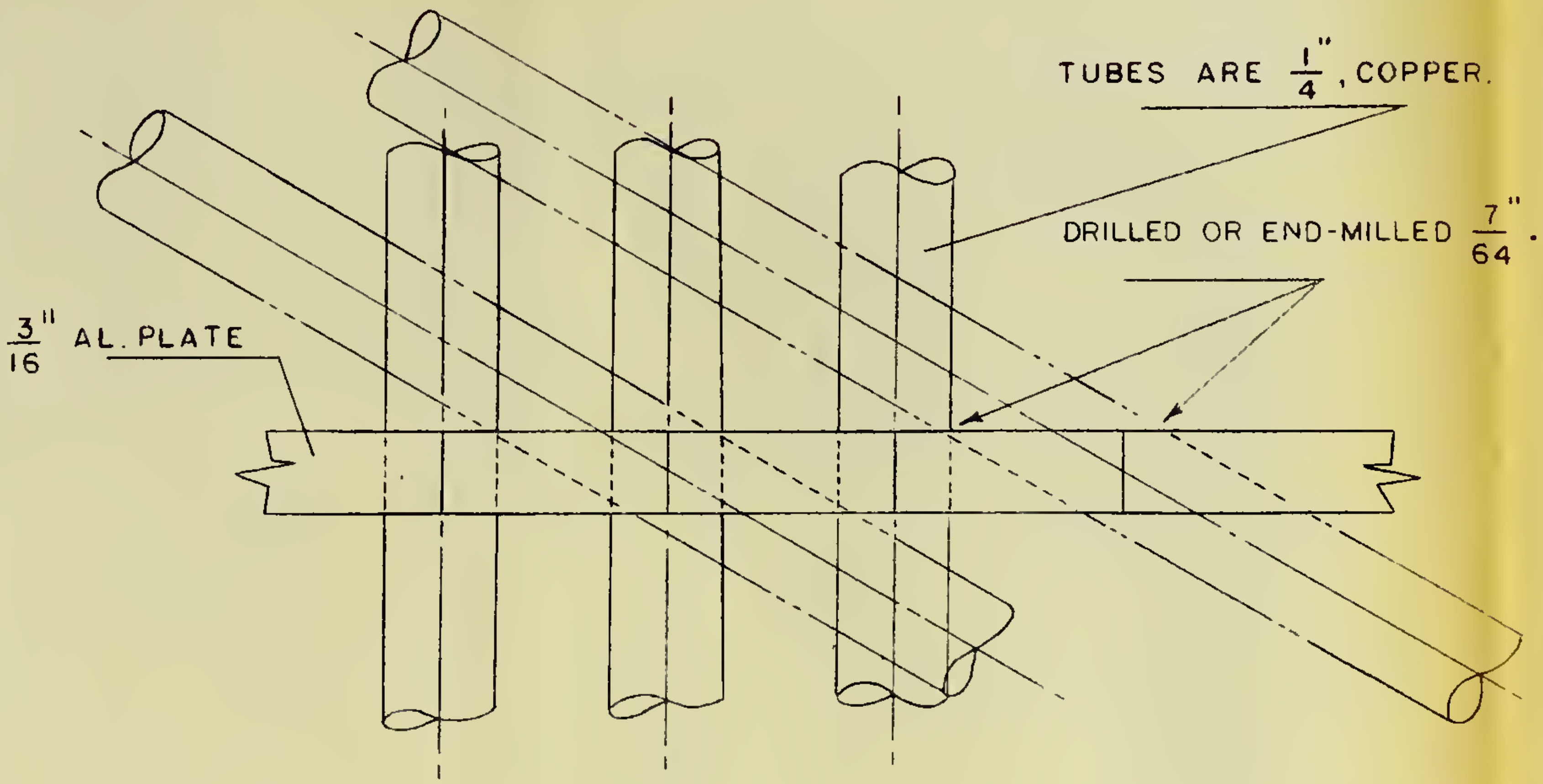


FIG. 16
TUBE BANK DETAIL
SCALE 1:3



TEST SECTION DRAWING

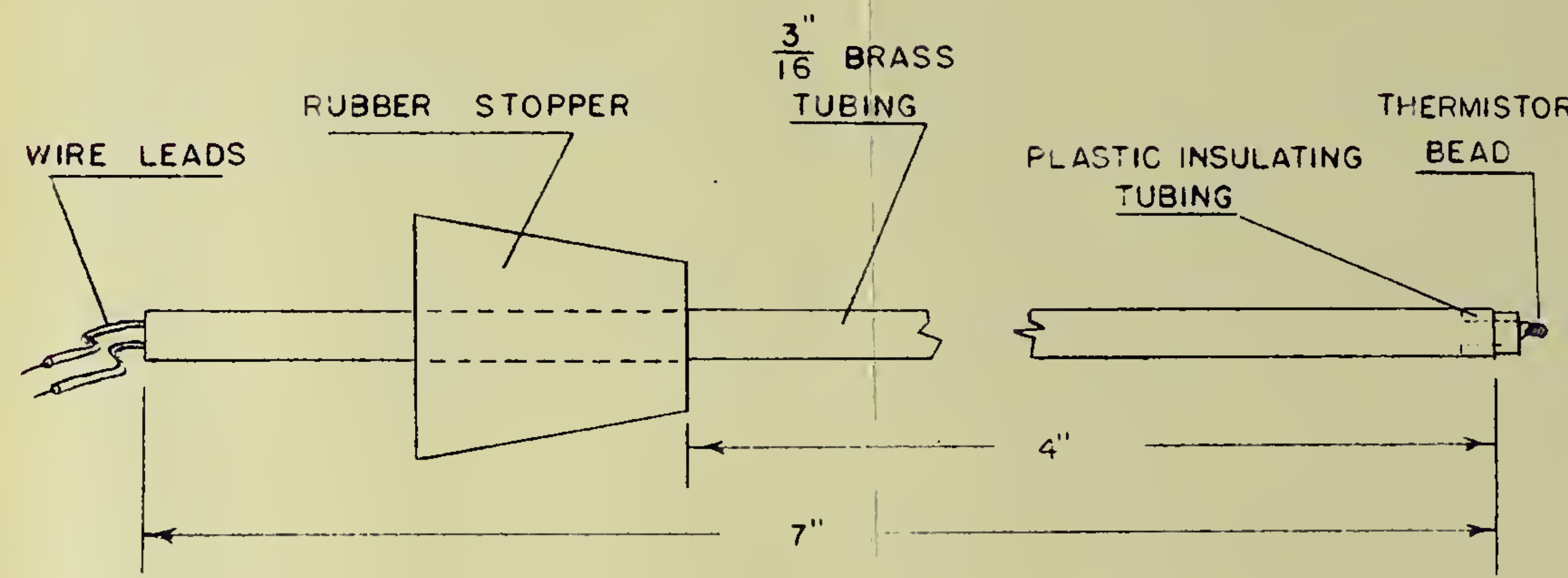
SCALE: $\frac{1}{4}$" = 1"   FIG. 17



DETAIL 'A'

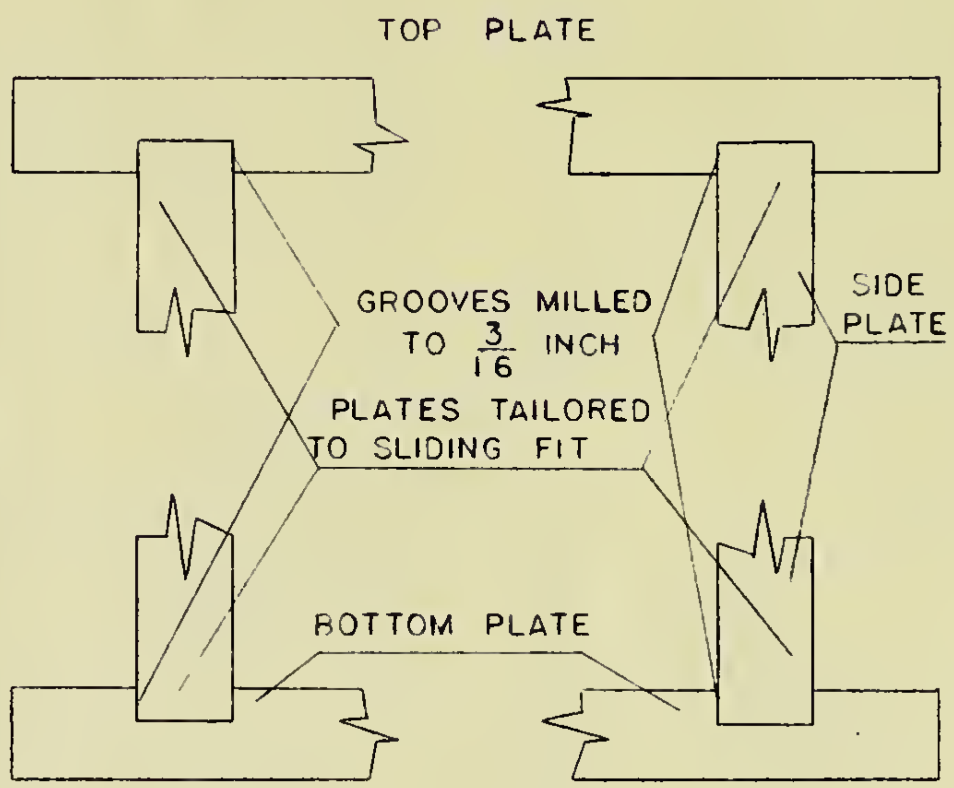
TUBE PENETRATION - SEALING STRIPS

TUBES SHOWN AT 90° AND 30°, $S_L = 2.0D$.



THERMISTOR PROBE

FULL SCALE



DETAIL 'B' - JOINTURE OF PLATES

TEST SECTION DETAILS

SCALE: 2"=1" EXCEPT AS NOTED

FIG. 18

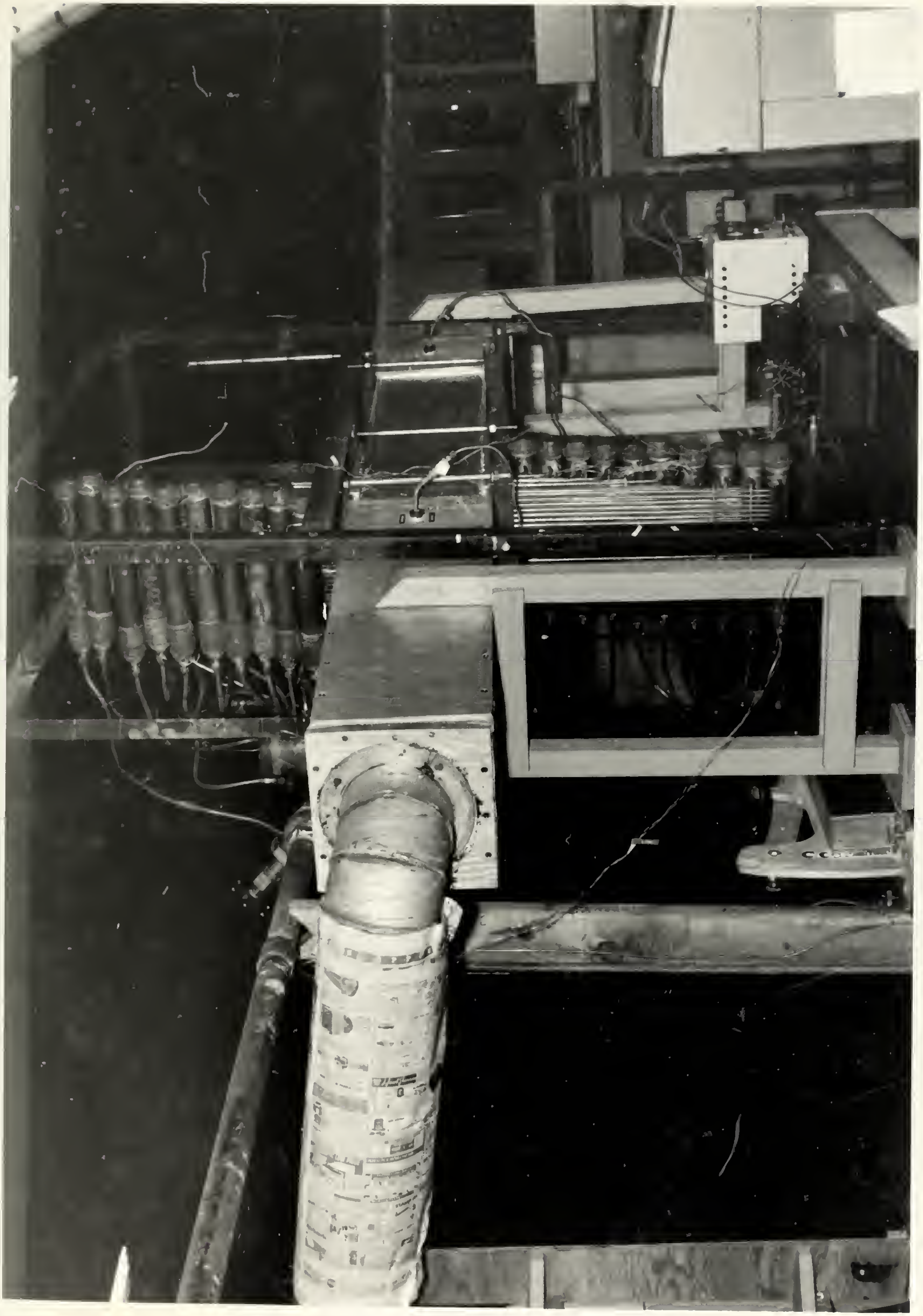


Fig. 19 Test Section Seen From Upstream End. Temperature Recording Instrumentation is Shown

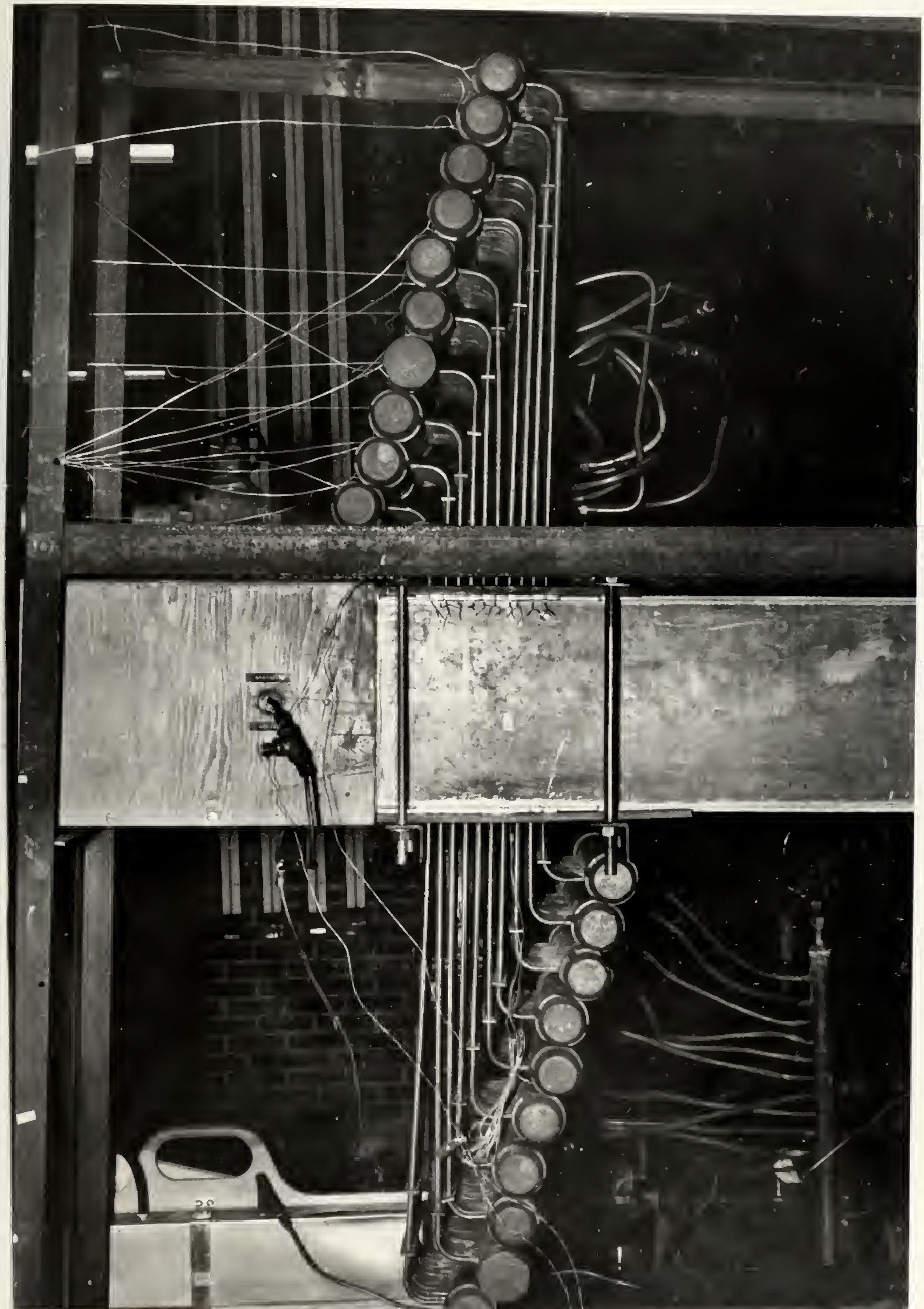


Fig. 20 Test Section in 90 Degree Configuration.

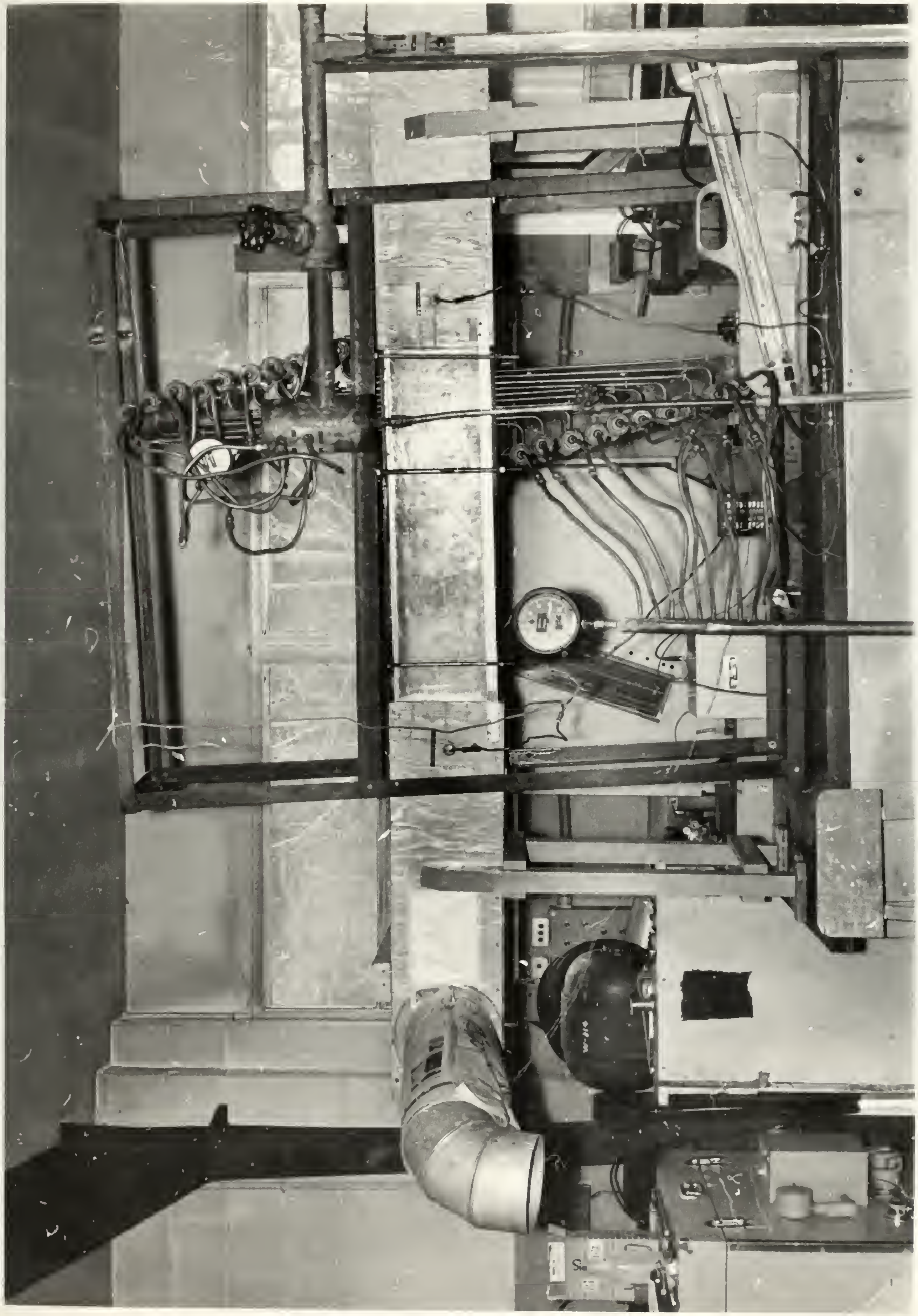


Fig. 21 Overall View of Test Section - 90 Degree Configuration

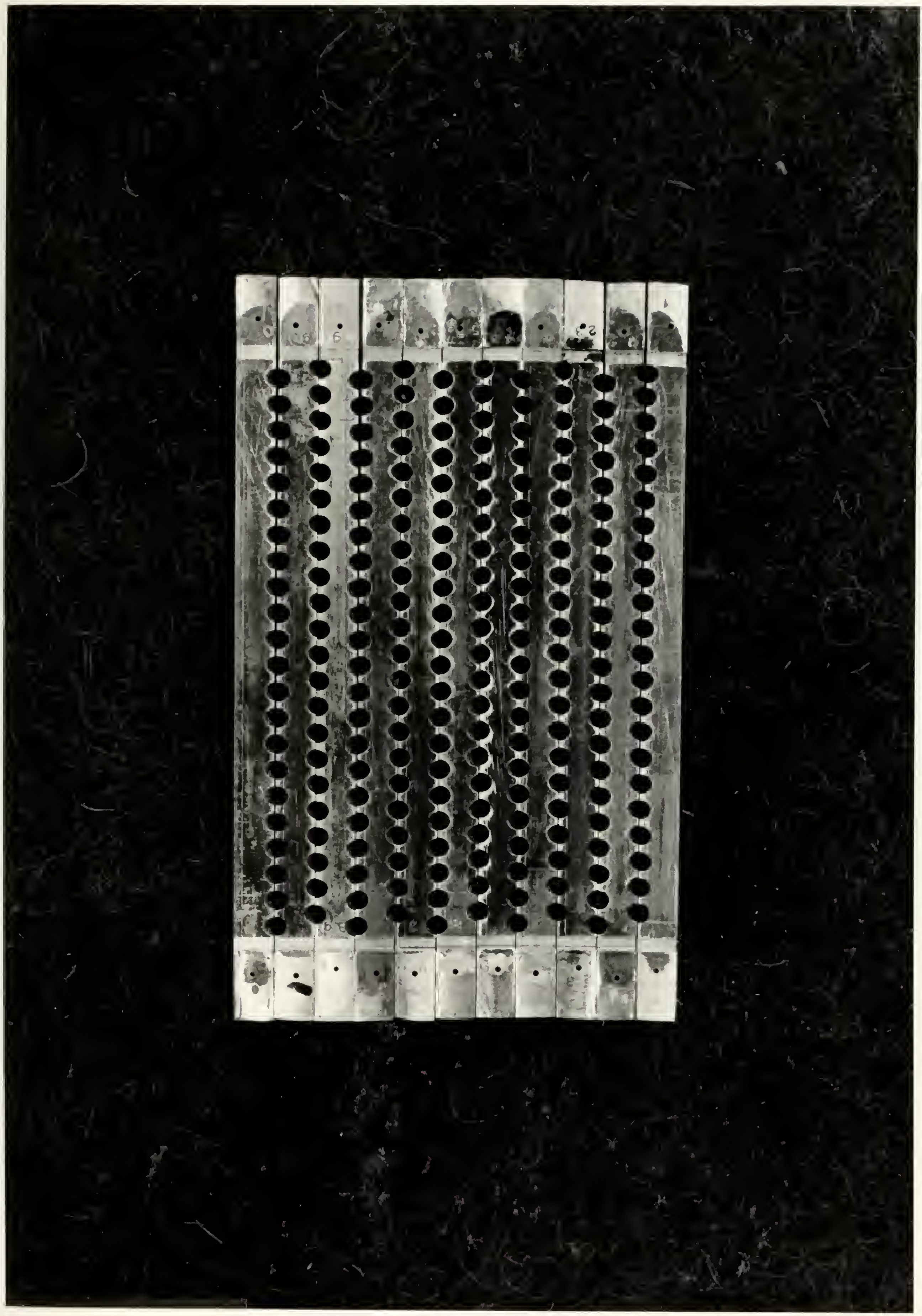


Fig. 22 Sealing Strips. Configuration Shown is $S_L = 2.0\ D_t$, $S_t = 1.5\ D_t$, Staggered Tubes, 60 Degree Inclination.

Instrumentation

Temperature

Instrumentation for obtaining temperature readings was by thermistors installed in air intake and exhaust lines and on tubes to sample temperatures throughout the tube bank.

Thermistors are solid state electronic semi-conductors which exhibit a large negative temperature coefficient of resistance. Their small physical size and the large negative temperature coefficient of resistance make thermistors particularly well suited for application in small scale experimental models as units can be located within a very limited space and great accuracy can be obtained with a relatively simple electrical circuit.

The thermistors used were Fenwal GB35J1 bead type thermistors. These units are 0.043 inches in diameter and have a nominal resistance of 5K ohms $\pm$ 20% at 25° C. The thermistors were calibrated by the use of a constant temperature bath. Boiling water and boiling benzene were used to obtain calibration beyond the range of the bath. A sample calibration curve is included as Figure 23 at the end of this section. Thermistors used for inlet and outlet temperatures were fitted into probes made from brass tubing and sealed with silicone rubber sealant. The probes were located in the center of the inlet and exhaust ducts at a point around a ninety degree bend from the tube bank so that they would be screened from direct

radiation from the tube bank. Some difficulty was experienced in affixing the thermistor units tightly to the tube bank so that a true tube temperature would be indicated. The problem was finally overcome by taping the thermistors to the tube with plastic electricians tape. Prior to placing the thermistor on the tube, a small groove was ground on the tube surface to receive the bead. The tape and pigtail leads were then covered with a high density epoxy. This effectively held the thermistor in place even during the curing period. Thermistor surface sensor assemblies consisting of thermistor beads bonded to teflon or silicone impregnated fiberglass tape are commercially available. The cost of these sensor assemblies is approximately eight tim s that of the thermistor units so that it was not considered economically feasible to use them. For similar reasons it was decided to undertake calibration of the units rather than to purchase units which track a standard curve within narrow limits.

The thermistor leads were connected to a selector switch which switched individual units into a Wheatstone Bridge circuit. The resistance necessary to balance the bridge was measured and this value was used to enter the calibration curves to determine temperatures in degrees Farenheit. A diagrammatic sketch of the temperature measuring circuit appears as Figure 24.

A high failure rate was experienced with the thermistor units. The highest percentage of failures were due to

accidental severing of the small diameter wire pigtails at the point where the wire entered the glass bead. These failures were caused simply by the rough service to which the units were subjected, particularly those installed on the tube surface. In addition, several thermistors were found to be erratic in behavior, culminating in a short circuit within the bead after a short time. No explanation for this performance has been found. Faulty units were replaced with spares until the supply was exhausted. At this time, it became necessary to replace the exhaust temperature thermistor with a mercury-in-glass thermometer.

As an aside, it should be added that the thermistors were not given fair trial in this application. The necessity to move the tube bank about roughly placed undue strain on these units. Based on this experience, hardy commercially prepared mounts such as those mentioned above are recommended.

Pressure

Instrumentation for pressure was by manometers containing oil or water as appropriate.

The manometer used to determine the pressure on the upstream side of the orifice was an open water manometer. The barometer reading was converted from inches of mercury to inches of water and added to the manometer reading to obtain an absolute pressure upstream of the orifice.

An oil filled U-tube differential manometer was used to indicate the pressure drop across the orifice plate. A water filled U-tube differential manometer and a slant tube manometer were used to measure the pressure drop across the tube bank.

A Bourdon tube pressure gauge and a bellows type compound gauge were used to measure steam inlet and drain pressures respectively.

Flow

Instrumentation for weight rate of flow was by thin plate orifice meter with pressure tops located at one pipe diameter preceeding and one half pipe diameter following the inlet face of the orifice plates. To obtain a large spectrum of Reynolds Numbers, three separate orifices of 2 inch, 3 inch, and 4 inch diameters were used. The weight rate of flow was obtained from the differential head across the orifice. It was found that it was possible to cover the entire range of weight rates of flow which could be obtained with the available steam turbo-blower with the 3 inch orifice.

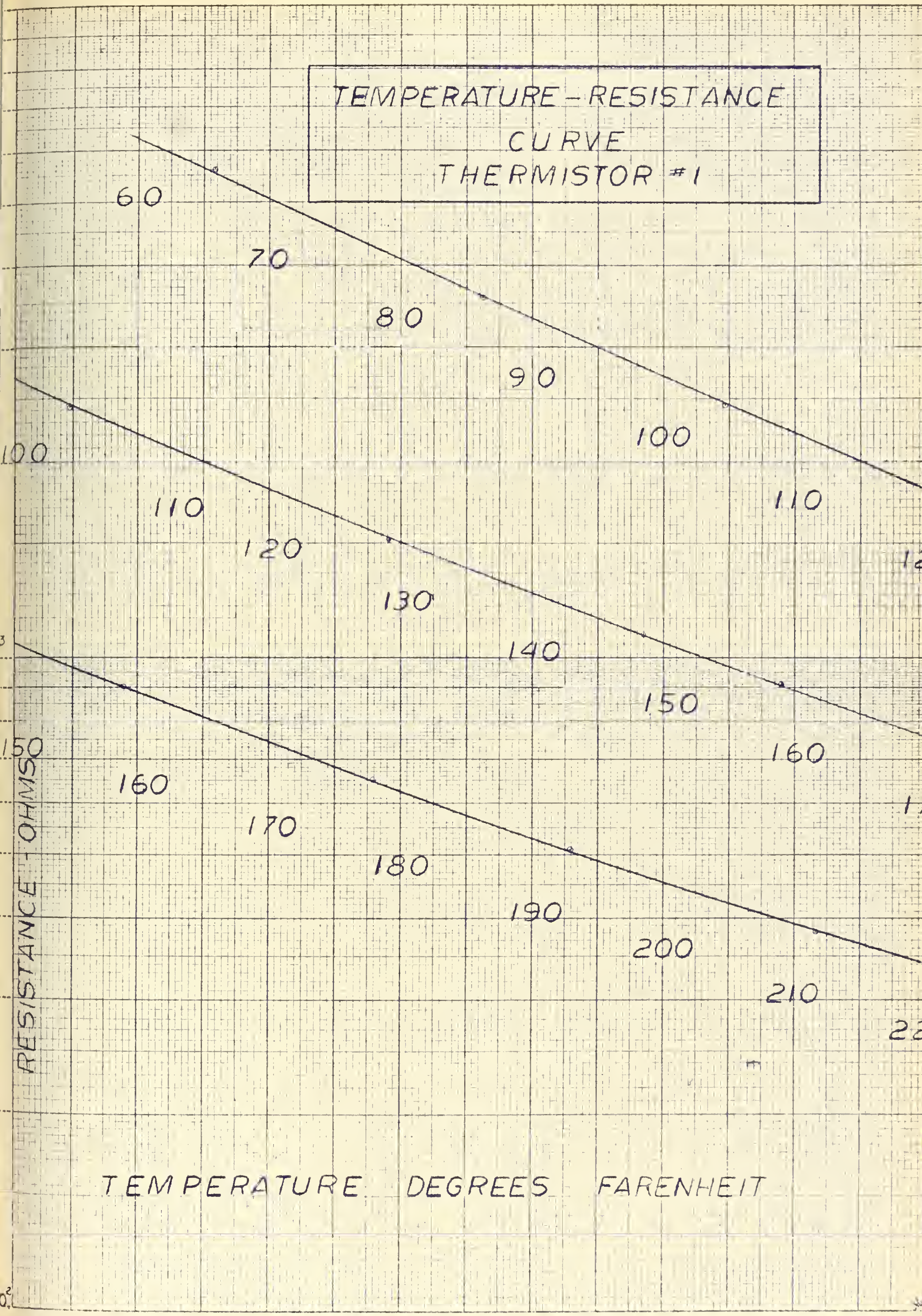
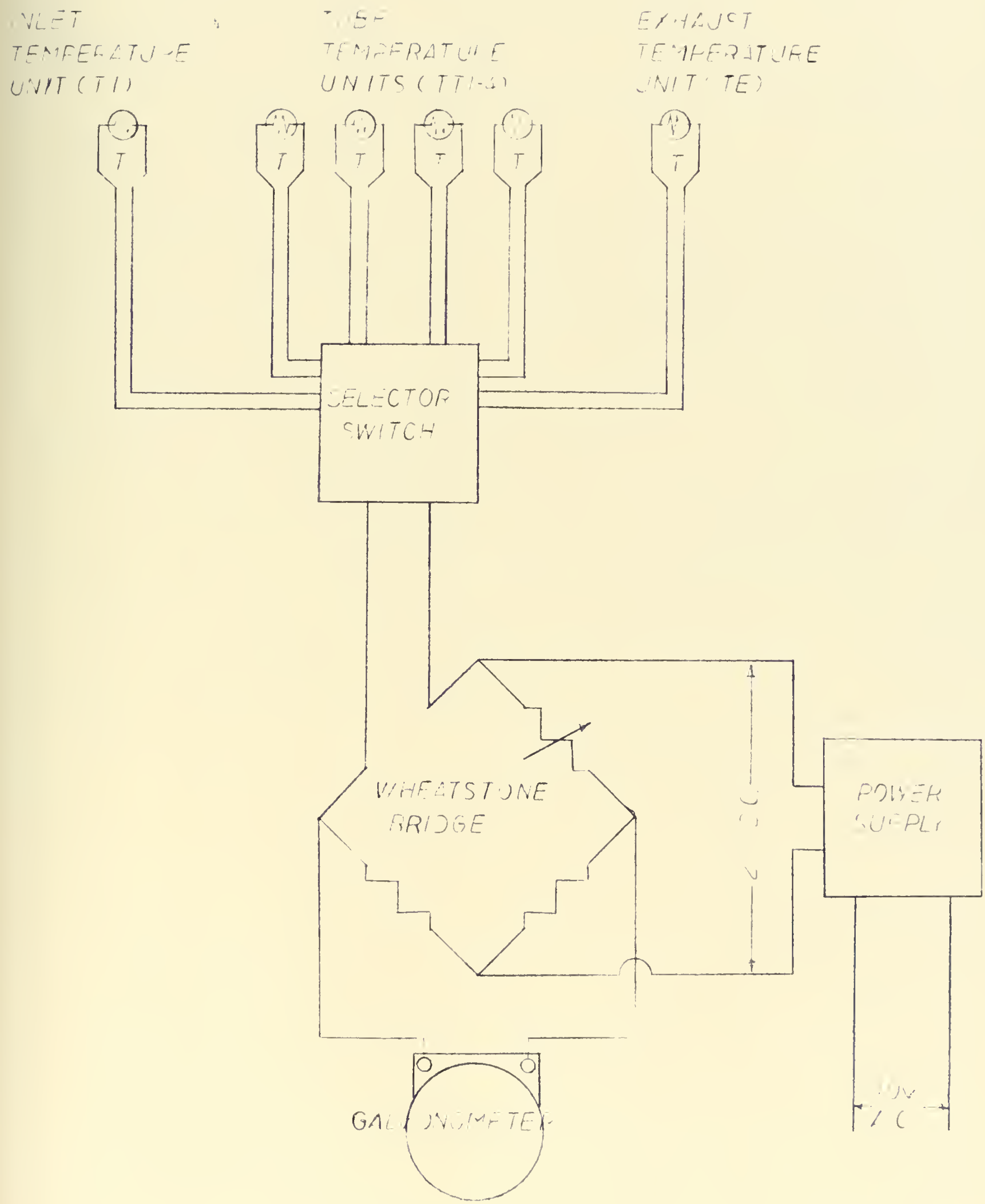

TEMPERATURE - RESISTANCE
CURVE
THERMISTOR #1
60
70
80
90
100
110
120
100
110
120
130
140
150
160
170
150
160
170
180
190
200
210
220
RESISTANCE - OHMS
TEMPERATURE DEGREES FARENHEIT

FIG. 23

TEMPERATURE
MEASURING
CIRCUIT
DIAGRAMMATIC

FIG 2.



APPENDIX B

Test Equipment Operating Procedure

Operation of the test equipment can be divided into two categories: 1) Lining up, lighting off and operation of the steam plant and auxiliary equipment and 2) Operation of the test apparatus itself.

The following procedure is followed in putting the steam plant into operation:

1) The cooling tower is checked and filled as necessary to ensure a proper quantity of cooling water.
2) Cooling tower fans and the circulating pump are started.
3) The condensate pump is started.
4) Fires are lighted in the boiler following the procedure given in the boiler operation and maintenance manual.
5) When the steam pressure has reached about 100 psi the air ejectors are lined up and sufficient nozzles cut in to maintain about ten inches of vacuum in the condenser. The most satisfactory operation was obtained when both second stage nozzles and no first stage nozzles were used.
6) The turbo blower is lighted off using a throttle pressure of about 5 psi. The blower lubricating oil tank should be checked to ensure that an adequate supply of lubricating oil is flowing.

7) The steam separator is drained and the tube bank steam supply and drain valves are opened. A pressure of ten psi at the steam separator was found to be very satisfactory.

When the above operations have been completed and the conditions in the apparatus as reflected by inlet, exhaust, and tube temperatures have stabilized the procedure enters its second phase, the collection of data.

Test procedure consists primarily of varying the quantity of amounts of air supplied to the apparatus and recording the data provided for by the installed instrumentation, as described in Appendix A.

The weight rate of flow of air to the test section is varied by throttling the blower supply steam with fine control being accomplished by manipulation of the discharge bleed valve. Satisfactory operation is obtained by starting at low flow rates and increasing gradually to high rates. With this procedure, the apparatus stabilizes quickly so that the interval between runs is very short. It should be noted that because the test section and the turbo blower are supplied by steam from the same line fluctuations in boiler pressure caused by variations in blower demand will cause fluctuations in the pressure to the tube banks. As the tube temperatures and exhaust temperatures are sensitive to the supply pressure variations should be minimized by ensuring the tube bank supply is the same before each run.

The pressure drop across the orifice is indicative of flow rate, accordingly successive runs may be made by adding small increments of pressure drop by throttling the blower.

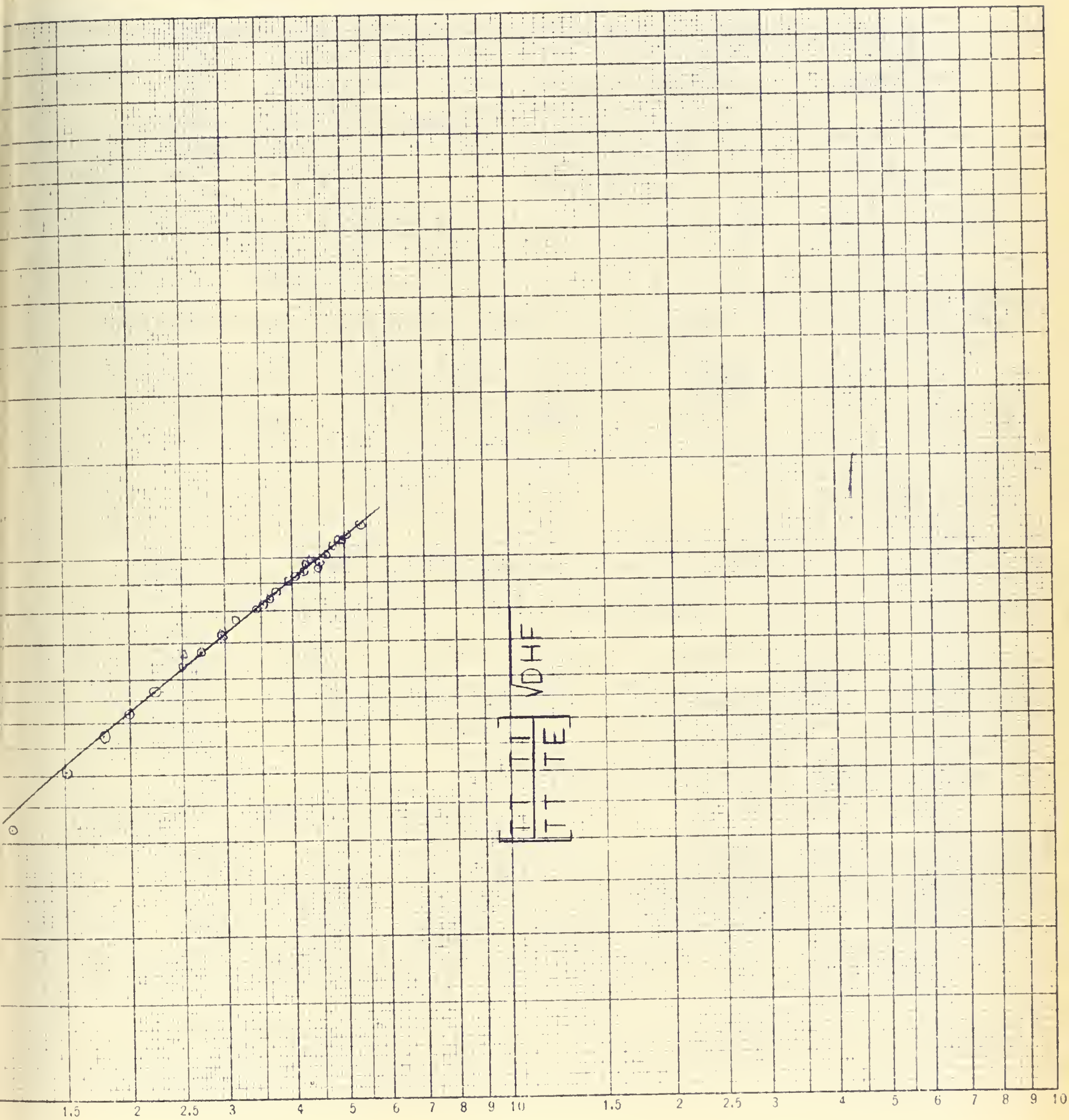
During testing, it is advantageous to make a running plot of the quantity $\frac{TT-TI}{TT-TE}\sqrt{DHF}$ versus $\sqrt{DHF}$ on full logarithmic paper. $\frac{TT-TI}{TT-TE}\sqrt{DHF}$ may be considered directly proportional to Nusselt Number while $\sqrt{DHF}$ may be considered directly proportional to Reynolds Number. A linear plot on full logarithmic paper then serves as a check on the consistency of the data. Care should be taken not to take such a plot as indicative of the validity or accuracy of the data as the proportionality is not exact. A sample plot appears as Figure 25 at the end of this Appendix.

Orifice plates of three different diameters are available for use with the apparatus. Utilization of the three inch orifice permits data to be taken over the entire range of flow obtainable with the turbo blower. The other two orifice sizes were not used.

If an immediate change of geometry is anticipated upon completion of data taking, allowing the blower to run after the steam supply to the tube bank has been secured cools the metal portions of the apparatus quickly and facilitates handling.

Securing procedure is essentially the reverse of the lighting off procedure. Upon securing in cold weather the cooling tower should be drained to prevent freezing of the pipes.

RUNS 2601-2626



$\sqrt{DHF}$

FIG 25

APPENDIX C

Development of Equations Used in Computations

Computerization of the calculation procedure required the development of equations for a number of quantities which are usually tabulated or taken from curves in engineering applications. Development of equations which are applicable in the range of temperatures and pressures which exist in the apparatus reduce the complexity of the program and permit a great saving in core storage within the machine. The quantities for which equations are developed herein are:

1) Thermal conductivity of air
2) Dynamic viscosity of air
3) Specific heat of wet air
4) Flow coefficients for orifice meters
5) Expansion factors for orifice meters
6) Grimison Arrangement factors
7) Nusselt Number by Colburn equation

The symbols used in this appendix are those developed for use in the computer program.

1) The thermal conductivity of air varies in an essentially linear manner in the range of temperatures which occur in the apparatus. An equation may be written in the form:

$$k = \frac{\Delta k}{\Delta T} \times T = C$$

Where

k = thermal conductivity of air in $\frac{\text{Btu}}{\text{hr-ft °F}}$

$\frac{\Delta k}{\Delta T}$ = change in thermal conductivity per degree Farenheit.

T = Temperature in degrees Farenheit

C = a constant

Values of thermal conductivity used to develop the equation were taken from Table 2 of <u>Gas Tables</u> by Keenan and Keys. [9] The equation for thermal conductivity is:

$$k = .000024\ (T-40) + .0144$$

or

$$k = 0.000024T + 0.01344$$

This equation gives values which correspond exactly with the tabulated values between 40 and 240 degrees Farenheit.

2) Dynamic viscosity, like thermal conductivity, varies linearly with temperature in the range of application and can be expressed in the same form:

$$\mu = \frac{\Delta\mu}{\Delta T} \times T + C$$

Where:

μ = dynamic viscosity in $\frac{\text{lbs}}{\text{sec-ft}}$

$\frac{\Delta\mu}{\Delta T}$ = change in dynamic viscosity per degree Farenheit

T = Temperature in degrees Farenheit

C = constant

Values used in the development of the equation were taken from Table 2 of <u>Gas Tables</u> by Keenan and Keyes. The equation for dynamic viscosity is:

$$\mu = \left[.16\ (T-40) + 119\right] \times 10^{-7}$$

or

$$\mu = \left[.16T + 112.6\right] \times 10^{-7}$$

3) The development of equations for specific heat of wet air at constant pressure requires the selection and adoption of applicable equations for the specific heats of air and water and combining them with proper weighting.

The equations selected were taken from Table I of <u>Thermodynamics</u> by Faires [10].

For dry air:

$$CPD = 0.219 + 0.342T \times 10^{-4} - .293T \times 10^{-8}$$

and for water:

$$CPH = 1.102 - 33.1T^{-\frac{1}{2}} + \frac{416}{T}$$

where: T = average temperature in the tube bank in degrees Rankine the specific heat of wet air is then determined by:

$$CPW = \frac{SPHU\ (CPH) + 7000\ CPD}{SPHU + 7000}$$

where: CPW = specific heat of wet air

CPD = specific heat of dry air

CPH = specific heat of water

SPHU = specific humidity in grains per pound

4) Flow Coefficients

For square edged thin plate orifice flow meters with taps one pipe diameter upstream and one half pipe diameter downstream the following equation for flow coefficient obtains:

$$AK = Ko + b$$

where:

AK = flow coefficient corresponding to any particular set of the parameters: pipe diameter (D), ratio of orifice diameter to pipe diameter (β), and pipe Reynolds number (ANRE)

Ko = Flow coefficient when pipe Reynolds number becomes infinite

b = an empirical multiplier

$$= \frac{1000}{\sqrt{ANRE}}$$

Ko and b may be expressed in the following forms:

$$Ko = (0.6014 - 0.01352\ D^{-\frac{1}{4}} + (0.3760 + 0.07257\ D^{-\frac{1}{4}} \left[\frac{0.00025}{D^2 \beta^2} + .0025D + \beta^4 + 1.5\beta^{16}\right]$$

$$b = (0.0002 + \frac{0.0011}{D}) + (0.0038 + \frac{0.0004}{D}) \times \left[\beta^2 + (16.5 + 5D\beta^{16})\right]$$

For situations such as exist in the test apparatus where there are a limited number of possible values of pipe diameter and diameter ratios specific values of Ko and b may be calculated and applied to the basic equation. It should be noted that although β^{16} represents a number less than unity raised to a relatively large power it cannot be ignored if acceptable accuracy is to be obtained.

The values for Ko and b for the various orifice plates available are:

Two inch orifice:

Ko = 0.59781

b = .00080

Three inch orifice:

ko = 0.6180

b = 0.00133

Four inch orifice:

Ko = 0.6735

b = 0.00229

The expressions for flow coefficients for each orifice then become:

Two inch orifice:

$$AK = 0.59781 + \frac{0.80}{ANRE}$$

Three inch orifice:

$$AK = 0.6180 + \frac{1.33}{\sqrt{ANRE}}$$

Four inch orifice:

$$AK = 0.6735 + \frac{2.29}{\sqrt{ANRE}}$$

5) Expansion Factor

The equation for the expansion factor through a square edged thin plate orifice meter with taps one diameter upstream and one half pipe diameter downstream may be expressed as:

$$V = 1 - (0.41 + 0.35\beta^4)\frac{X}{K}$$

where: β = ratio of orifice diameter to pipe diameter

X = ratio of differential pressure to absolute static inlet pressure

K = ratio of specific heats.

If a constant value of K = 1.4 is assumed and values of β^4 are calculated for the two, three and four inch orifice meters the equation reduces to:

For 2" orifice: $Y = 1 - .295X$

For 3" orifice: $Y = 1 - .307X$

For 4" orifice: $Y = 1 - .339X$

For utilization in the program the factor X must be expressed in the same units as the input data. The numerator X is equal to the differential pressure across the orifice

meter (DHF) which is in inches of oil. The denominator is equal to the sum of the barometric pressure (PB) expressed in inches of mercury and the pressure above barometric ahead of the orifice meter (P_1) expressed in inches of water. All units will be converted to inches of water so the expression for X becomes:

$$X = \frac{0.827DHF}{P_1 + 13.596PB}$$

where: DHF, P_1, and PB are input quantities as defined in the preceeding paragraph.

0.827 = the specific gravity of the oil used in the manometer

13.596 = the conversion factor from inches of mercury to inches of water.

Inserting the expression for X and simplifying the expressions for expansion factor as used in the calculation are obtained:

For 2" orifice:

$$Y = 1 - \frac{0.24464\ DHF}{P_1 + 13.596PB}$$

For 3" orifice:

$$Y = 1 - \frac{0.25457\ DHF}{P_1 + 13.596PB}$$

For 4" orifice:

$$Y = 1 - \frac{.28131\ DHF}{P_1 + 13.596PB}$$

6) Grimison Arrangement Factors

The arrangement factors used in the Grimison Equation are a function of longitudinal and transverse pitches, Reynolds Number and the arrangement (staggered or in-line) of the tube

bank, and are not amenable to a simple analytic expression. However as only one transverse pitch, 1.5 tube diameters, and a limited number of combinations of back pitch and arrangement were tested it was found feasible to plot arrangement factor as a function of Reynolds Number only for each geometry. The curves so plotted were parabolic in form. An equation of the form C_1 (BNRE)^2 + C_2 (BNRE) + C_3 = ARGFAC could be written for each of them by utilizing the LaGrange Method. The equations so developed are of the form:

$$\text{ARGFAC} = C_1\,(\text{BNRE})^2 + C_2\,(\text{BNRE}) + C_3$$

where:

GEOMETRY	$C_1 \times (10)^{10}$	$C_2 \times (10)^5$	C_3
$S_T = S_L = 1.5\ D_t$ IN-LINE	.463	-.2963	1.063
$S_T = S_L = 1.5\ D_t$ STAGGERED	-1.29	.3462	.94059
$S_T = 2.0\ D_t$, $S_L = 1.5\ D_t$ IN-LINE	5.7407	-1.774	1.10518
$S_T = 2.0\ D_t$, $S_L = 1.5\ D_t$ STAGGERED	4.074	-1.574	1.1698

Nusselt Number by the Colburn Equation

In order to establish a lower limit which would be comparable to parallel flow the Colburn equation was used to calculate Nusselt Number. The Colburn equation is:

$$\frac{h_f D_h}{K} = .023 \left(\frac{GD_h}{\mu}\right)^{.8} \left(\frac{CPW\mu}{K}\right)^{1/3}$$

where:

$\frac{GD_h}{\mu}$ = Reynolds Number based on hydraulic diameter.

For the Colburn Nusselt Number to be directly comparable with those developed experimentally or by the Grimison equation it

must be based on tube diameter rather than hydraulic diameter. To accomplish this both sides of the equation are multiplied by the ratio of tube diameter to hydraulic diameter.

$$\frac{h_f D_H}{K} \; \frac{D_t}{D_H} = 0.023 \left(\frac{G D_H}{\mu}\right)^{0.80} \left(\frac{D_t}{D_H}\right) \left(\frac{CPW\,\mu}{k}\right)^{1/3}$$

$$\frac{h_f D_t}{k} = 0.023 \left(\frac{G D_t}{\mu}\right)^{0.80} \left(\frac{D_t}{D_H}\right)^{0.20} \left(\frac{CPW\,\mu}{k}\right)^{1/3}$$

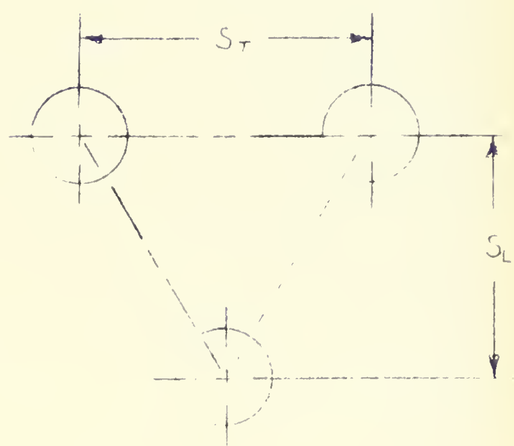
in the nomenclature used

$$CNNU = 0.023\ (BNRE)^{0.80} \left(\frac{D_t}{D_H}\right)^{0.20} \left(\frac{CPW\,\mu}{k}\right)^{1/3}$$

The hydraulic diameter is defined as four times the free flow area divided by the wetted perimeter. For a staggered tube arrangement:

$$D_H = 4 \left[\frac{\dfrac{S_T S_L}{2} - \dfrac{\pi D_t^{\,2}}{2(4)}}{\dfrac{\pi D_t}{2}}\right]$$

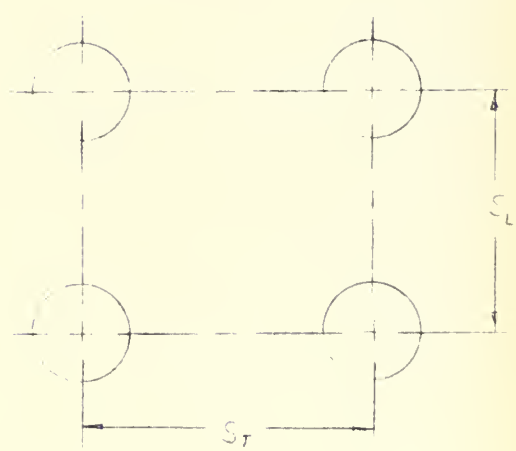
$$D_H = 4 \; \frac{S_T S_L - \pi D_t^{\,2}}{\pi D_t}$$



For the in-line arrangement:

$$D_H = 4 \left[\frac{S_T S_L - \pi D_T^{\,2}}{\pi D_t}\right]$$

$$D_H = \frac{4\ S_T S_L - \pi D_t^{\,2}}{\pi D_t}$$



Since only one value of S_T and two values of S_L are considered, the hydraulic diameter can be numerically evaluated for these values. For $S_T = 1.5D_t$, $S_L = 1.5D_t$

$$D_H = \frac{4\ (1.5D_t)^2 - D_t^2\pi}{D_t\pi}$$

$$D_H = \left(\frac{9-\pi}{\pi}\right) \quad D_t$$

Similarly for St = $1.5D_t$, Dl = $2.0D_t$

$$D_H = \left(\frac{12-\pi}{\pi}\right) \quad D_t$$

The factor $\left(\frac{D_t}{D_h}\right)^{0.20}$ then can be evaluated for a particular geometry. This factor has been given the name DIAFAC and is included in the Colburn equation to give it the form:

$$CNNU = .023\ (BNRE)^{0.80}\ (DIAFAC)\ \left(\frac{CPW\mu}{k}\right)^{1/3}$$

APPENDIX D

Experimental Data Reduction

Program Description

The computer program described herein is a FORTRAN IV program designed for use with the IBM 7090 data processing system. The program calculates Nusselt Number, Reynolds Number and frictional resistance coefficient for varying flow angles from experimentally derived data in the Haeberle Laboratory, Webb Institute. The constants and to some degree the method used are particularized to the apparatus used for data collection.

The first step in the program is to calculate the sines of the angles of inclination at which tests were conducted and to assign to them floating point variable names in order that they may be repeatedly called without recalculation of the sine function.

Control of the program is achieved through a DO loop utilizing the variable M which represents the sequential number of a set of data being processed. It is required that the maximum value of M called KASES be supplied as input each time the program is used. The value of M's incremented by one each time a set of data is processed. The DO statement refers the machine to a READ statement causing a new set of data to be read in and processed. When the maximum value of M (M= KASES) is reached the program is completed.

Required input to the program is:

1) Run code number, a four digit fixed point variable, (IRCN)

2) Pressure drop across the thin plate orifice meter in inches of oil a three or four digit floating point variable, (DHF).

3) Pressure above atmospheric ahead of the orifice meter in inches of water, a three or four digit floating point variable, (P1).

4) Barometric pressure in inches of mercury, a four digit floating point variable, (PB).

5) Pressure drop across the tube bank in inches of water, a three or four digit floating point variable, (DP).

6) Temperature of the inlet air in degrees Farenheit, a three digit floating point variable, (TI).

7) Temperature of the exhaust air in degrees Farenheit, a four digit floating point variable, (TE).

8) Temperature of the tube surfaces in degrees Farenheit, a four digit floating point variable, (TT).

9) The diameter of the orifice plate in inches, a single digit fixed point variable, (IDO).

10) The specific humidity of the inlet air in grains per pound, a three digit floating point variable, (SPHU).

11) A geometry factor indicating whether the tube geometry is staggered or in-line, a single digit fixed point variable, (LGF).

12) An angle factor indicating the angle of inclination of the tube bank, a single digit fixed point variable, (LANGLE).

13) Back pitch factor, indicating whether the back pitch is 1.5D or 2.0D, single digit fixed point variable (LAF)

The program first calculates the intermediate quantity V for use in the pipe Reynolds Number calculation.

The program then queries the value of orifice diameter to determine the path to be taken in calculating the Reynolds Number thru the orifice. The constants chosen for calculating the expansion factor and flow coefficients are functions of the diameter of the orifice meter. The procedure followed is the same for all orifice diameters. A value of flow coefficient (AK) is assumed, and a value of V is calculated.

The three quantities which have been calculated are multiplied together to determine an initial estimate of Reynolds Number.

When an estimate of Reynolds Number has been made a better estimate of flow coefficient is obtained.

The estimate of flow coefficient is then compared to the initial value. If the two values vary by one half of one per cent or less the calculated value of BK is taken as the value of the flow coefficient and the value of Reynolds Number is accepted and the calculation continues. If the difference between the two values of flow coefficients is greater than one half of one per cent the calculated value of flow coefficient is used for an initial value for recalculation of Reynolds Number and flow coefficient. This process continues until the one half of one per cent criterion is reached.

When satisfactory values of Reynolds Number and flow coefficient have been established the program proceeds by

squaring the orifice diameter and converting it to a floating point variable for use in the weight rate of flow calculation. Weight rate of flow is then calculated.

The average temperature in the tube bank is calculated and converted to degrees Rankine. With this average temperature the specific heats of dry air and water are calculated and combined to determine the specific heat of the air in the apparatus.

Log mean temperature difference and film temperature are then calculated.

All quantities necessary for the calculation of Nusselt Number are now available and line quantity is calculated.

The angle factor (LANGLE) is used to select the proper value of the sine of the angle of inclination previously calculated. This sine function is then multiplied by the calculated Nusselt Number to determine the Nusselt Number for the angled configuration.

The Reynolds Number in the tube bank is calculated.

The Program then queries the geometry factor to determine if the geometry is staggered or in-line and branches accordingly to calculate film temperature for the friction factor computation.

Reynolds Number for use in the friction factor calculation is calculated.

The density of the air in the apparatus and the friction factor are calculated.

After the friction factor has been computed the program again queries the geometry factor and then queries the back pitch factor to determine the geometry so that the proper arrangement factor and diameter factor for use in the Grimison and Colburn equations can be computed. When the arrangement factor has been selected and computed it is employed in the Grimison equation to calculate a value of Nusselt Number. The value of Nusselt Number calculated by the Grimison equation is divided into that obtained by use of the experimental data. A value of Nusselt Number is calculated using the Colburn equation.

All computations have been completed so that an output tape may be written. Output consists of:

1) Run Code Number as read in (IRCN)
2) Nusselt Number determined from experimental data (BNNU)
3) Nusselt Number determined from the Grimison equation (T NU)
4) Nusselt Number determined from the Colburn equation (CNNU)
5) The ratio between the two Nusselt Numbers (FTHETA)
6) Reynolds Number based on the film temperature used in the Nusselt Number calculation (BNRE)
7) Friction factor (FRIFAC)
8) Reynolds Number using the film temperature used in the friction factor calculation.

Upon completion of writing the output data another set of data is read in and the program repeated. With the 7090 system calculation of each set of data requires about one seventh of one second.

A block diagram of the program is presented herewith. The block diagram is a graphic representation of the data processing system procedures used in the solution of the problem. The diagram is included to assist the reader with a visual record of operational and logic steps in the program and the relationship each step in the program has to the solution.

The symbols used in the diagram are the standard IBM symbols representing machine functions. A Key to these symbols is included in the Nomenclature section.

A program listing also follows the block diagram.

The computer facilities used for these computations were those at the David Taylor Model Basin. Data was prepared using equipment available at Webb Institute.

BASIC DATA COMPUTATION — COMPUTER PROGRAM BLOCK DIAGRAM

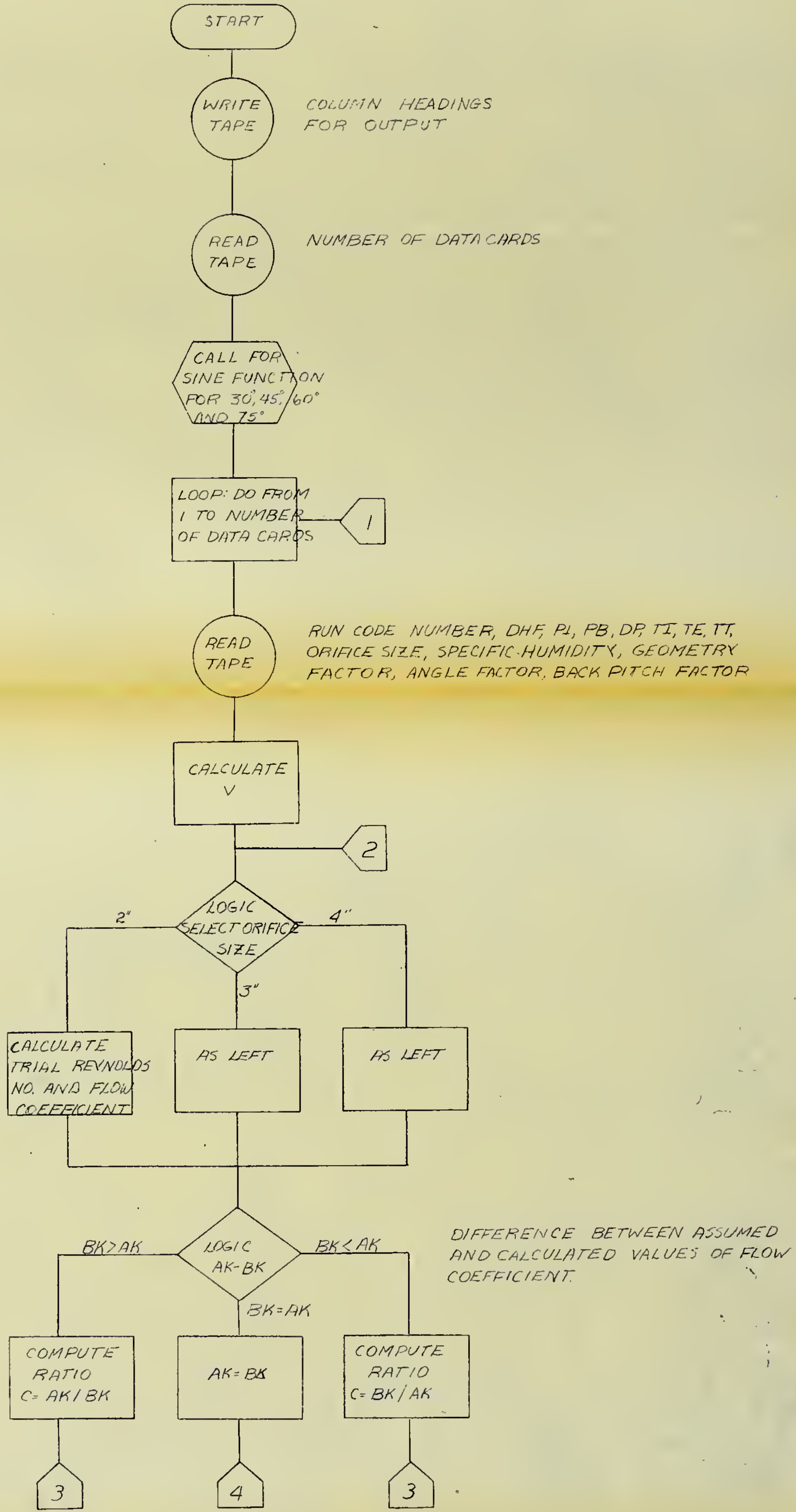


FIG. 26A

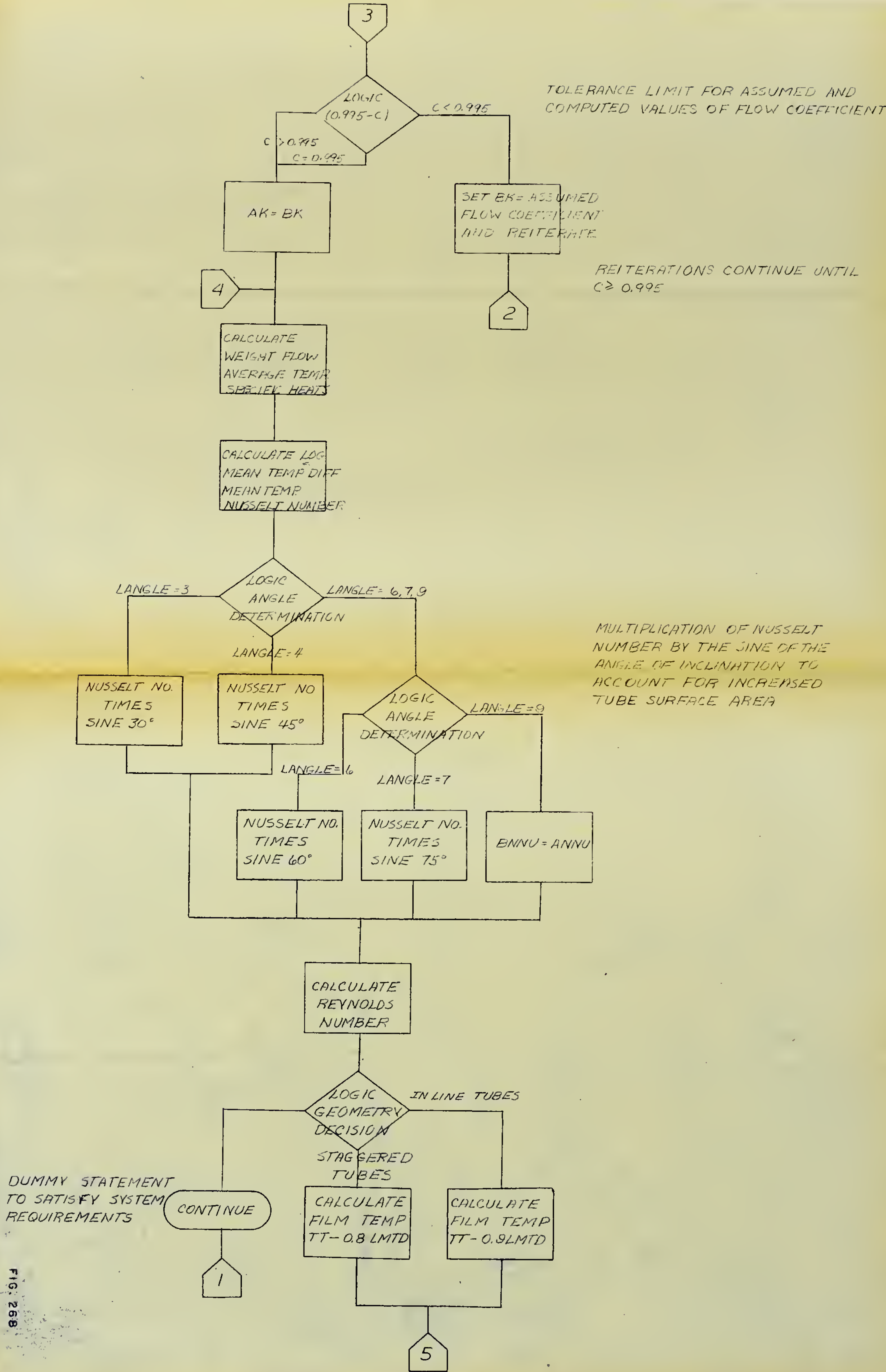

3
LOGIC (0.995 - C)
C > 0.995
C = 0.995
C < 0.995
TOLERANCE LIMIT FOR ASSUMED AND COMPUTED VALUES OF FLOW COEFFICIENT
AK = BK
SET BK = ASSUMED FLOW COEFFICIENT AND REITERATE
REITERATIONS CONTINUE UNTIL C ≥ 0.995
2
4
CALCULATE WEIGHT FLOW AVERAGE TEMP SPECIFIC HEATS
CALCULATE LOG MEAN TEMP DIFF MEAN TEMP NUSSELT NUMBER
LOGIC ANGLE DETERMINATION
LANGLE = 3
LANGLE = 6, 7, 9
LANGLE = 4
MULTIPLICATION OF NUSSELT NUMBER BY THE SINE OF THE ANGLE OF INCLINATION TO ACCOUNT FOR INCREASED TUBE SURFACE AREA
NUSSELT NO. TIMES SINE 30°
NUSSELT NO TIMES SINE 45°
LOGIC ANGLE DETERMINATION
LANGLE = 9
LANGLE = 6
LANGLE = 7
NUSSELT NO. TIMES SINE 60°
NUSSELT NO. TIMES SINE 75°
BNNU = ANNU
CALCULATE REYNOLDS NUMBER
LOGIC GEOMETRY DECISION
IN LINE TUBES
STAGGERED TUBES
DUMMY STATEMENT TO SATISFY SYSTEM REQUIREMENTS
CONTINUE
CALCULATE FILM TEMP TT - 0.8 LMTD
CALCULATE FILM TEMP TT - 0.9 LMTD
1
5

FIG. 26B

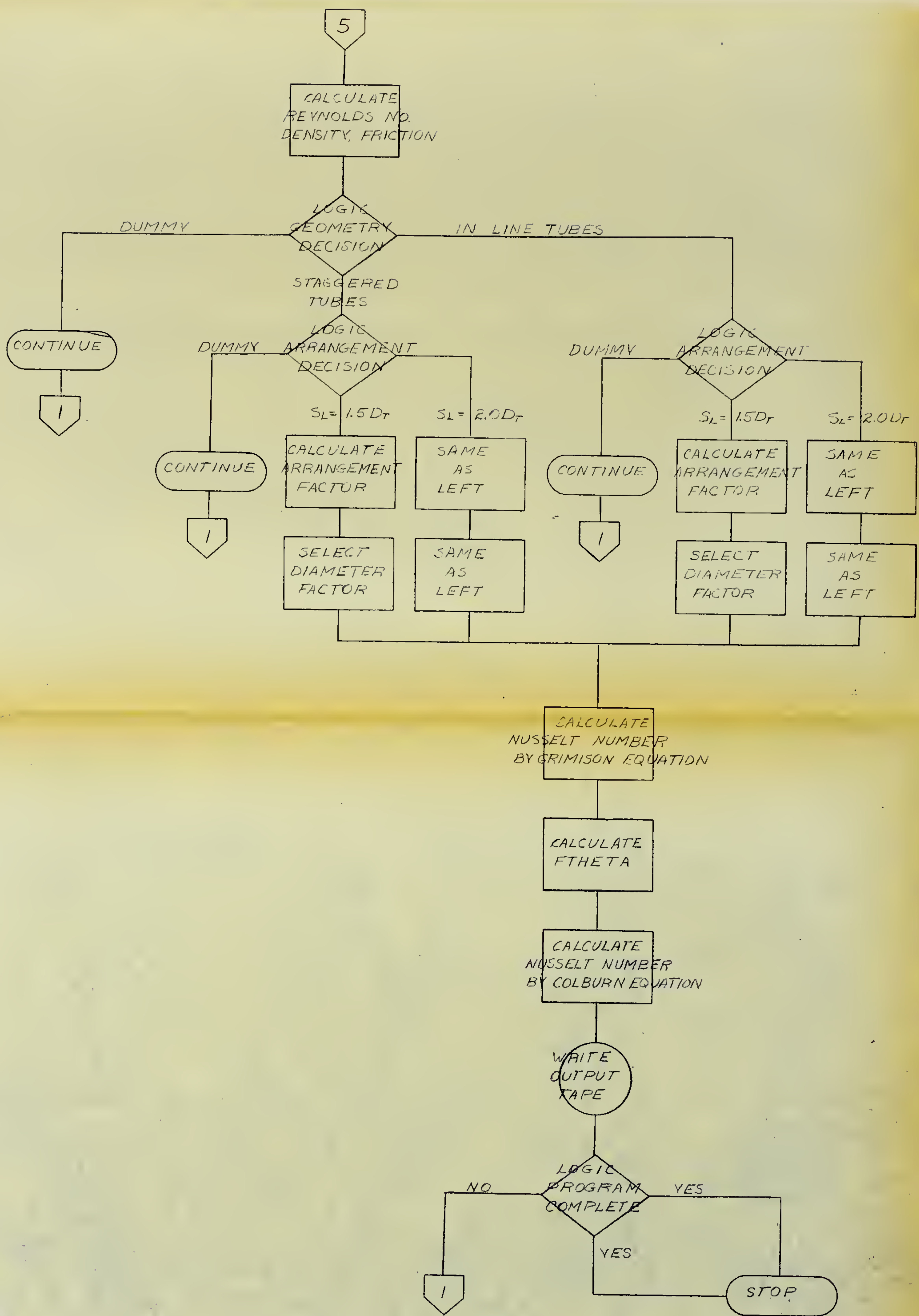

5
CALCULATE REYNOLDS NO. DENSITY, FRICTION
LOGIC GEOMETRY DECISION
DUMMY
IN LINE TUBES
STAGGERED TUBES
CONTINUE
1
LOGIC ARRANGEMENT DECISION
DUMMY
$S_L = 1.5 D_T$
$S_L = 2.0 D_T$
CONTINUE
1
CALCULATE ARRANGEMENT FACTOR
SAME AS LEFT
SELECT DIAMETER FACTOR
SAME AS LEFT
LOGIC ARRANGEMENT DECISION
DUMMY
$S_L = 1.5 D_T$
$S_L = 2.0 D_T$
CONTINUE
1
CALCULATE ARRANGEMENT FACTOR
SAME AS LEFT
SELECT DIAMETER FACTOR
SAME AS LEFT
CALCULATE NUSSELT NUMBER BY GRIMISON EQUATION
CALCULATE FTHETA
CALCULATE NUSSELT NUMBER BY COLBURN EQUATION
WRITE OUTPUT TAPE
LOGIC PROGRAM COMPLETE
NO
YES
YES
1
STOP

FIG. 26C

```
      FORTRAN PROGRAM TO CALCULATE NUSSELT NUMBER, REYNOLDS NUMBER, AND
     1FRICTION FACTOR IN A CONVECTION BANK USING EXPERIMENTAL DATA
    1 FORMAT(I )
    2 FORMAT(1H1,3X,3 HRUN          EXP          SIM          COL/3X,78HCODE    NUS
     1SELT    NUSSELT    NUSSELT    FTHETA    REYNOLDS  FRICTION  REYNOLDS(
     2F)    )
    3 FORMAT(I4,3F7.2,F7.3,F6.1,2F7.1,I3,F6.1,I4,I3)
    4 FORMAT( X,I4,2X,F8.4,2X,F8.4, X,F .4,2X,F8. ,2X,F9. ,2X,F9.6,2X,F9
     1.2)
      SIN =SIN( . 36)
      SIN4=SIN( .7854)
      SIN6=SIN(1. 472)
      SIN7=SIN(1.3  )
      READ (5,1) KASE
      NT=
   19 DO    M=1,KASE
      IF(NT)1  ,1  ,17
  1   WRITE(6,2)
      NT=.4
   17 READ(5, )IRCN,DHF,P1,P8,DP,TI,T ,TT,IDD,SPHU,LGF,LANGLE,LAF
      V=( .234/(( .16*TI)+112.6))*(1.   7)
      IF(IDD- )5,6,7
    5 AK= .6
      Y=(1.  -( .24464*DHF)/(P1+13.596*P8))*SQRT(DHF)
   14 ANRE=AK*V*Y
      BK= .59761+ .8  /SQRT(ANRE)
      GO TO 8
    6 AK= .62
      Y=(1.  -( .25457*DHF)/(P1+13.596*P8))*SQRT(DHF)
   15 ANRE=AK*V*Y
      BK= .61  +1.23/SQRT(ANRE)
      GO TO 8
    7 AK= .68
      Y=(1. -( .28131*DHF)/(P1+13.596*P8))*SQRT(DHF)
   16 ANRE=AK*V*Y
      BK= .67  +2.  /SQRT(ANRE)
    8 IF(AK-BK)9,1 ,11
   11 C=BK/AK
      GO TO 12
    9 C=AK/BK
   12 IF( .99 -C)1 ,1 ,13
   13 AK=BK
      IF(IDD-3)14,15,16
   1  AK= K
      WI=IDD**2
      WAU= 6. 78*WI*AK*Y
      TAVG=(TI+TE)/2.  +459.69
      CPD= .21 +( .34 *TAVG/1.  4)-( .29 *TAVG**2/1.  )
      CPH=1.1 2-(33.1/SQRT(TAVG))+(41 . /TAVG)
      CPW=((SPHU*CPH)+(7.  .  *CPD))/(SPHU+7.   . )
      XLMTD=(T -TI)/ALOG((TT-TI)/(TT-T ))
      TF=((TE+TI)/2. +TT)/2.
      ANNU=(WAU*CPW*(TE-TI))/(XLMTD*( . 11 8*TF+6.4929))
      IF(LANGLE-4)24,25,24
   24 BNNU=ANNU*SIN3
```

```
      GO TO 3
25    BNNU=ANNU*SIN4
      GO TO 3
26    IF(LANGLE-7)27,28,29
27    BNNU=ANNU*SIN6
      GO TO 3
28    BNNU=ANNU*SIN7
      GO TO 3
29    BNNU=ANNU
3     BNRE=WAU*(1. E2)/(( . 46256*TF)+32.552)
      IF(LGF) .21,22
21    TFF=TT-( .8 *XLMTD)
      GO TO 23
22    TFF=TT-( .90 *XLMTD)
23    CNRE=(WAU*(1. E2))/((. 46256*TFF)+32.552)
      RHO=((P1+13.596*PB)*.1815)/(53.349*(TFF+459.69))
      FRIFAC=(1.384*RHO*DE*(1. E8))/((AO/ .1673)**2)
      IF(LGF) ,31,32
31    IF(LAF) ,33,34
32    IF(LAF) ,35,36
33    ARGFAC=(4. 74*(BNRE**2))/(1.E1 )-(1.574*(BNRE ))/(1. E5)+1.1698
331   DIAFAC= .883
      GO TO 37
34    ARGFAC=(5.74 7*(BNRE**2))/(1. E1 )-(1.774*(BNRE))/(1. E5)+1.1 51
341   DIAFAC= .5278
      GO TO 37
35    ARGFAC= .94 58+(3.45 *BNRE)/1. E6-( .129*(BNRE**2))/1.E9
351   DIAFAC= .883
      GO TO 37
36    ARGFAC=(4.63*(BNRE** ))/1. E11-( .96 *BNRE)/1.E +1. 36
361   DIAFAC= .8278
37    TNNU=(BNRE** .6 )* . 92*ARGFAC*(((CP *3. *( .16*TF+112.6))/((1.E4
     1)*( . 24*TF+ . 1344)))** .333)
      FTHETA= NNU/TNNU
38    CNNU=(TNNU* . 7 77*( NRE** . )*DIAFAC)/ARGFAC
      WRITE(6,4) IRCN,BNNU,TNNU,CNNU,FTHETA,BNRE,FRIFAC,CNRE
      NT=NT-1
20    CONTINUE
      STOP
      END
```

APPENDIX E

Experimental Data

This Appendix presents a listing of all test data. The data is listed sequentially by run code numbers. No labels are provided on the data listings, accordingly the following information is provided:

Column	Description
1	Run code number for data point identification, four digits, (RNCD).
2	Pressure drop across the thin plate orifices, inches of oil, three or four digits (DHF)
3	Pressure ahead of the thin plate orifice, inches of water, three or four digits (P_1)
4	Barometric pressure, inches of mercury, four digits (PB)
5	Pressure drop across the tube bank inches of Mercury, four digits (DP)
6	Inlet temperature, degrees Farenheit, four digits (TI)
7	Exhaust temperature, degrees Farenheit, four digits (TE)
8	Tube surface temperature, degrees Farenheit, four digits, (TT).
9	Orifice diameter, inches (IDO)
10	Specific humidity, grains per pound (SPHU)
11	Geometry indicator (LGF)
12	Angle indicator (LANGLE)
13	Arrangement indicator (LAF)

1401	1.40	1.00	30.46	0.100	80.0	176.0	212.0	3	77.0	0	4	0
1402	1.50	1.40	29.70	0.340	70.0	166.0	212.0	4	87.0	0	4	0
1403	1.70	1.20	30.46	0.120	78.0	174.0	212.0	3	77.0	0	4	0
1404	1.70	1.00	29.70	0.100	79.0	176.0	212.0	3	94.0	0	4	0
1405	2.00	1.20	29.95	0.160	72.0	165.0	212.0	3	70.0	0	4	0
1406	2.00	1.60	30.46	0.130	72.0	163.0	212.0	3	77.0	0	4	0
1407	2.50	1.20	30.46	0.120	78.0	174.0	212.0	3	77.0	0	4	0
1408	2.50	1.80	29.70	0.490	72.0	162.0	212.0	4	87.0	0	4	0
1409	2.70	1.60	29.95	0.130	72.0	163.0	212.0	3	70.0	0	4	0
1410	2.80	1.90	29.70	0.180	79.0	167.0	212.0	3	94.0	0	4	0
1411	2.90	2.00	30.46	0.130	72.0	163.0	212.0	3	77.0	0	4	0
1412	3.30	2.00	29.95	0.160	72.0	164.0	212.0	3	70.0	0	4	0
1413	3.90	2.40	29.70	0.210	79.0	176.0	212.0	3	94.0	0	4	0
1414	4.10	2.50	29.95	0.210	73.0	163.0	212.0	3	70.0	0	4	0
1415	4.20	3.00	30.46	0.210	73.0	163.0	212.0	3	77.0	0	4	0
1416	4.30	3.20	29.70	0.800	72.0	162.0	212.0	4	87.0	0	4	0
1417	4.90	3.00	29.95	0.230	73.0	162.0	212.0	3	70.0	0	4	0
1418	4.90	3.00	30.46	0.230	74.0	162.0	212.0	3	77.0	0	4	0
1419	5.70	3.60	29.95	0.310	74.0	165.0	212.0	3	70.0	0	4	0
1420	6.20	4.00	29.70	0.360	79.0	168.0	212.0	3	94.0	0	4	0
1421	6.50	4.00	30.46	0.570	74.0	160.0	212.0	3	77.0	0	4	0
1422	7.80	5.00	29.70	0.390	79.0	167.0	212.0	3	94.0	0	4	0
1423	8.30	6.20	29.70	1.550	78.0	155.0	212.0	4	87.0	0	4	0
1424	8.30	5.20	30.46	0.390	75.0	157.0	212.0	3	77.0	0	4	0
1425	8.50	6.40	29.70	1.630	80.0	157.0	212.0	4	87.0	0	4	0
1426	9.60	6.50	30.46	0.570	78.0	160.0	212.0	3	77.0	0	4	0
1427	11.40	7.60	29.70	0.620	80.0	162.0	212.0	3	94.0	0	4	0
1428	13.10	9.20	30.46	0.670	80.0	161.0	212.0	3	77.0	0	4	0
1429	16.00	9.80	29.70	0.830	82.0	160.0	212.0	3	94.0	0	4	0
1430	16.10	10.50	30.46	0.830	82.0	159.0	212.0	3	77.0	0	4	0
1431	18.40	12.20	30.46	0.830	83.0	158.0	212.0	3	77.0	0	4	0
1432	20.50	13.60	30.46	1.040	84.0	159.0	212.0	3	77.0	0	4	0
1433	24.00	16.00	30.46	1.220	85.0	156.0	212.0	3	77.0	0	4	0
1434	25.50	16.80	29.70	1.300	84.0	156.0	212.0	3	94.0	0	4	0
1435	29.10	19.20	30.46	1.400	87.0	156.0	212.0	3	77.0	0	4	0
1436	33.00	22.00	30.46	1.610	88.0	155.0	212.0	3	77.0	0	4	0
1601	1.10	0.50	30.48	0.200	74.0	171.0	212.0	3	62.0	0	6	0
1602	1.60	1.20	30.48	0.400	75.0	164.0	212.0	3	62.0	0	6	0
1603	2.60	1.60	30.48	0.500	76.0	165.0	212.0	3	62.0	0	6	0
1604	2.90	2.40	29.82	1.100	81.0	166.0	212.0	3	46.0	0	6	0
1605	3.30	2.00	30.48	0.800	76.0	165.0	212.0	3	62.0	0	6	0
1606	4.10	2.60	30.48	0.900	77.0	164.0	212.0	3	62.0	0	6	0
1607	5.00	3.30	30.48	1.200	78.0	161.0	212.0	3	62.0	0	6	0
1608	6.00	4.00	30.48	1.400	78.0	160.0	212.0	3	62.0	0	6	0
1609	6.40	4.20	29.82	1.900	82.0	162.0	212.0	3	46.0	0	6	0
1610	7.00	4.60	30.48	1.700	78.0	158.0	212.0	3	62.0	0	6	0
1611	7.20	5.00	29.82	2.100	81.0	161.0	212.0	3	46.0	0	6	0
1612	8.10	5.40	29.82	2.400	82.0	161.0	212.0	3	46.0	0	6	0
1613	8.30	5.40	30.48	1.700	78.0	158.0	212.0	3	62.0	0	6	0
1614	9.40	6.40	30.48	2.500	80.0	155.0	212.0	3	62.0	0	6	0
1615	10.00	6.60	29.82	2.800	82.0	160.0	212.0	3	46.0	0	6	0
1616	11.60	7.40	29.82	3.200	83.0	160.0	212.0	3	46.0	0	6	0
1617	11.60	6.80	30.48	2.900	81.0	156.0	212.0	3	62.0	0	6	0
1618	12.60	8.60	30.48	4.000	83.0	154.0	212.0	3	62.0	0	6	0
1619	12.90	8.80	29.82	3.600	83.0	159.0	212.0	3	46.0	0	6	0

1620	14.60	9.80	29.82	4.200	84.0	158.0	212.0	3	46.0	0	6	0
1621	15.20	10.60	30.48	4.000	83.0	154.0	212.0	3	46.0	0	6	0
1622	16.50	11.00	29.82	4.500	82.0	156.0	212.0	3	46.0	0	6	0
1623	17.90	12.30	29.82	5.000	83.0	156.0	212.0	3	46.0	0	6	0
1624	18.60	12.60	29.82	5.000	84.0	157.0	212.0	3	46.0	0	6	0
1625	18.60	12.80	30.48	5.300	84.0	153.0	212.0	3	46.0	0	6	0
1626	20.50	14.00	29.82	5.700	87.0	155.0	212.0	3	46.0	0	6	0
1627	22.30	15.20	29.82	5.900	84.0	157.0	212.0	3	46.0	0	6	0
1628	23.40	15.90	30.48	6.100	85.0	154.0	212.0	3	62.0	0	6	0
1629	24.40	16.60	29.82	6.500	86.0	155.0	212.0	3	46.0	0	6	0
1630	26.00	17.80	30.48	7.000	86.0	154.0	212.0	3	62.0	0	6	0
1631	26.40	18.20	29.82	7.000	86.0	154.0	212.0	3	46.0	0	6	0
1701	1.20	0.80	29.61	0.400	74.0	166.0	212.0	3	42.0	0	7	0
1702	2.20	1.60	29.61	0.600	74.0	160.0	212.0	3	42.0	0	7	0
1703	3.30	2.00	29.61	1.200	75.0	159.0	212.0	3	42.0	0	7	0
1704	4.20	2.60	29.61	1.500	76.0	159.0	212.0	3	42.0	0	7	0
1705	5.30	3.50	29.61	2.000	77.0	158.0	212.0	3	42.0	0	7	0
1706	6.30	4.10	29.61	2.400	77.0	158.0	212.0	3	42.0	0	7	0
1707	7.20	4.80	29.61	2.500	78.0	157.0	212.0	3	42.0	0	7	0
1708	8.40	5.60	29.61	2.900	79.0	158.0	212.0	3	42.0	0	7	0
1709	9.30	6.30	29.61	3.400	80.0	156.0	212.0	3	42.0	0	7	0
1710	10.70	8.00	29.61	3.900	81.0	156.0	212.0	3	42.0	0	7	0
1711	12.50	8.90	29.61	4.300	82.0	154.0	212.0	3	42.0	0	7	0
1712	14.40	10.10	29.61	4.800	82.0	153.0	212.0	3	42.0	0	7	0
1713	16.40	11.60	29.61	5.500	83.0	153.0	212.0	3	42.0	0	7	0
1714	18.20	13.00	29.61	6.000	84.0	153.0	212.0	3	42.0	0	7	0
1715	20.10	14.30	29.61	6.800	85.0	153.0	212.0	3	42.0	0	7	0
1716	23.20	16.50	29.61	7.800	86.0	153.0	212.0	3	42.0	0	7	0
1717	26.70	18.50	29.61	8.900	87.0	153.0	212.0	3	42.0	0	7	0
1718	28.90	19.90	29.61	9.700	89.0	153.0	212.0	3	42.0	0	7	0
1901	2.80	2.00	30.34	0.310	80.0	169.0	212.0	3	84.0	0	9	0
1902	3.90	3.90	30.34	1.740	86.0	156.0	212.0	4	84.0	0	9	0
1903	6.80	6.70	30.34	2.850	87.0	152.0	212.0	4	84.0	0	9	0
1904	9.00	6.13	30.34	3.000	83.0	157.0	212.0	3	84.0	0	9	0
1905	10.90	10.60	30.34	4.540	91.0	152.0	215.0	4	84.0	0	9	0
1906	16.00	11.70	30.34	4.000	86.0	155.0	210.0	3	84.0	0	9	0
1907	27.20	19.40	30.34	5.220	91.0	154.0	212.0	3	84.0	0	9	0
1901	25.00	29.40	30.08	1.000	104.0	151.0	204.0	4	50.0	0	9	0
1902	20.5	24.40	30.08	1.00	91.0	145.0	208.0	4	50.0	0	9	0
1903	18.0	22.6	30.08	1.0	89.0	145.0	210.0	4	50.0	0	9	0
1904	9.0	12.2	30.08	1.0	76.0	144.0	210.0	4	50.0	0	9	0
1905	20.05	22.0	29.75	1.0	92.0	147.0	215.0	4	68.0	0	9	0
1906	17.25	19.12	29.75	1.0	90.0	146.0	210.0	4	68.0	0	9	0
1907	14.38	17.4	29.75	1.0	87.0	146.0	205.0	4	68.0	0	9	0
1908	7.88	10.42	29.75	1.0	80.0	149.0	210.0	4	68.0	0	9	0
1909	6.25	5.22	29.75	1.0	78.0	150.0	212.0	4	68.0	0	9	0
1910	5.5	8.7	29.75	1.0	77.0	151.0	215.0	4	68.0	0	9	0
1911	3.88	0.0	29.75	1.0	76.0	152.0	215.0	4	68.0	0	9	0
1912	20.62	25.0	29.68	8.78	96.5	145.0	212.0	4	71.0	0	9	0
1913	17.12	21.0	29.68	7.37	94.0	145.5	212.0	4	71.0	0	9	0
1914	12.63	15.5	29.68	6.25	89.5	146.5	212.0	4	71.0	0	9	0
1915	11.12	13.5	29.68	5.12	88.0	149.0	212.0	4	71.0	0	9	0
1916	5.5	6.87	29.68	2.63	83.0	153.0	212.0	4	71.0	0	9	0
1917	4.75	6.25	29.68	2.37	82.5	153.0	212.0	4	71.0	0	9	0
1918	1.63	2.50	29.68	0.88	82.0	161.0	212.0	4	71.0	0	9	0

1919	24.62	22.50	29.95	2.9	90.5	155.5	212.0	4	85.0	0	9	0
1920	17.0	15.62	29.95	2.33	88.0	157.0	212.0	4	85.0	0	9	0
1921	10.62	9.72	29.95	1.44	88.5	161.0	212.0	4	85.0	0	9	0
1922	7.12	9.75	29.95	1.01	84.0	164.5	212.0	4	85.0	0	9	0
1923	3.75	3.75	29.95	0.55	83.0	169.0	212.0	4	85.0	0	9	0
1924	1.70	1.62	29.95	0.310	82.0	170.5	212.0	4	85.0	0	9	0

2301	1.90	1.35	29.78	0.039	68.0	173.5	213.0	3	57.3	1	3	0
2302	2.58	1.80	29.78	0.049	66.1	171.5	210.7	3	57.3	1	3	0
2303	5.05	3.37	29.78	0.083	68.0	164.6	205.0	3	57.3	1	3	0
2304	6.85	4.55	29.78	0.052	69.1	164.3	207.4	3	57.3	1	3	0
2305	8.20	5.40	29.78	0.130	72.3	163.4	206.3	3	57.3	1	3	0
2306	10.95	7.30	29.78	0.213	73.2	160.5	204.1	3	57.3	1	3	0
2307	12.10	8.10	29.78	0.311	75.7	160.3	203.3	3	57.3	1	3	0
2308	15.30	10.25	29.78	0.467	77.4	159.9	203.1	3	57.3	1	3	0
2309	17.35	11.65	29.78	0.622	80.3	159.2	202.5	3	57.3	1	3	0
2310	21.30	14.38	29.78	0.831	82.1	157.3	201.0	3	57.3	1	3	0
2311	23.90	16.00	29.78	1.012	85.2	157.1	200.0	3	57.3	1	3	0
2312	24.95	16.81	29.78	1.075	87.5	159.4	203.5	3	57.3	1	3	0
2313	20.20	13.51	29.78	0.817	82.6	161.8	208.0	3	57.3	1	3	0
2314	14.90	9.90	29.78	0.520	81.6	164.5	210.5	3	57.3	1	3	0
2315	19.10	6.10	29.78	0.181	77.1	168.1	214.6	3	57.3	1	3	0
2316	4.40	2.78	29.78	0.103	75.3	175.6	214.0	3	57.3	1	3	0
2401	1.42	0.93	30.15	0.072	66.4	168.9	221.8	3	52.2	1	4	0
2402	1.96	1.29	30.15	0.119	65.4	167.0	222.5	3	52.2	1	4	0
2403	3.05	2.01	30.15	0.307	64.8	163.8	217.9	3	52.2	1	4	0
2404	4.08	2.73	30.15	0.376	65.4	161.4	216.7	3	52.2	1	4	0
2405	5.08	3.38	30.15	0.510	65.7	161.3	216.9	3	52.2	1	4	0
2406	6.17	4.10	30.15	0.598	66.5	160.0	215.6	3	52.2	1	4	0
2407	7.17	4.78	30.15	0.647	67.2	158.8	214.6	3	52.2	1	4	0
2408	8.40	5.57	30.15	0.740	67.4	157.0	213.0	3	52.2	1	4	0
2409	9.22	6.18	30.15	0.810	68.3	156.0	216.2	3	52.2	1	4	0
2410	10.41	6.99	30.15	0.978	69.0	154.0	210.8	3	52.2	1	4	0
2411	10.93	7.41	30.15	1.027	69.2	158.0	215.8	3	52.2	1	4	0
2412	12.17	8.20	30.15	1.136	69.6	154.0	211.2	3	52.2	1	4	0
2413	13.25	8.96	30.15	1.209	70.0	152.8	210.5	3	52.2	1	4	0
2414	14.29	9.68	30.15	1.294	70.7	152.3	210.7	3	52.2	1	4	0
2415	15.20	10.23	30.15	1.343	70.8	152.8	210.5	3	52.2	1	4	0
2416	15.98	10.80	30.15	1.436	70.9	152.0	209.8	3	52.2	1	4	0
2417	17.50	11.83	30.15	1.574	72.5	151.0	210.2	3	52.2	1	4	0
2418	18.71	12.67	30.15	1.705	73.0	152.0	210.0	3	52.2	1	4	0
2419	19.22	13.20	30.15	1.765	74.8	152.1	209.9	3	52.2	1	4	0
2420	20.35	13.72	30.15	1.812	74.9	152.0	209.4	3	52.2	1	4	0
2421	1.90	1 .8	30.15	1.938	76.3	151.0	208.9	3	52.2	1	4	0
2422	22.90	15.51	30.15	2.016	77.1	151.1	208.8	3	52.2	1	4	0
2424	24.88	16.80	30.15	2.164	79.3	151.0	208.4	3	52.2	1	4	0
2425	26.25	17.66	30.15	2.276	79.3	151.0	208.4	3	52.2	1	4	0
2426	27.35	18.45	30.15	2.345	80.4	150.8	207.3	3	52.2	1	4	0
2427	28.40	19.10	30.15	2.487	82.7	150.9	207.2	3	52.2	1	4	0
2428	29.00	20.56	30.15	2.487	82.7	150.9	207.2	3	52.2	1	4	0
2601	1.35	0.85	30.36	0.204	64.8	161.0	217.0	3	59.2	1	6	0
2602	2.28	1.50	30.36	0.303	65.5	159.2	214.9	3	59.2	1	6	0
2603	3.20	2.06	30.36	0.329	66.4	158.0	214.1	3	59.2	1	6	0
2604	3.98	2.64	30.36	0.399	67.0	157.0	213.7	3	59.2	1	6	0
2605	4.98	3.30	30.36	0.518	68.4	156.7	214.0	3	59.2	1	6	0
2606	6.27	4.19	30.36	0.665	69.6	157.0	214.0	3	59.2	1	6	0
2607	7.48	5.10	30.36	0.841	71.0	154.6	212.0	3	59.2	1	6	0
2608	8.82	5.90	30.36	1.048	73.5	155.0	212.3	3	59.2	1	6	0
2609	10.00	6.74	30.36	1.190	74.0	155.4	212.8	3	59.2	1	6	0
2610	11.62	7.88	30.36	1.343	75.9	154.0	211.9	3	59.2	1	6	0
2611	12.55	8.43	30.36	1.465	76.9	154.0	212.9	3	59.2	1	6	0
2612	13.18	8.90	30.36	1.501	77.5	153.2	210.6	3	59.2	1	6	0

2613	14.07	9.54	30.36	1.618	78.5	153.0	210.4	3	59.2	1	6	0
2614	15.40	10.59	30.36	1.791	80.2	153.6	210.6	3	59.2	1	6	0
2615	16.60	11.25	30.36	1.887	81.5	153.4	210.3	3	59.2	1	6	0
2616	17.70	11.95	30.36	1.993	83.1	152.9	209.5	3	59.2	1	6	0
2617	18.00	12.10	30.36	2.076	84.5	154.8	210.7	3	59.2	1	6	0
2618	19.85	13.75	30.36	2.249	87.0	155.8	211.7	3	59.2	1	6	0
2619	20.20	14.62	30.36	2.290	88.2	154.8	211.5	3	59.2	1	6	0
2620	21.80	14.82	30.36	2.428	88.5	154.0	209.3	3	59.2	1	6	0
2621	22.30	15.00	30.36	2.487	89.1	156.3	211.6	3	59.2	1	6	0
2622	23.95	16.28	30.36	2.681	90.5	155.1	210.3	3	59.2	1	6	0
2623	24.85	16.80	30.36	2.746	91.3	155.0	210.3	3	59.2	1	6	0
2624	25.75	17.37	30.36	2.836	92.4	155.0	209.4	3	59.2	1	6	0
2625	28.50	19.25	30.36	3.113	95.3	156.5	210.4	3	59.2	1	6	0
2626	18.80	12.80	30.36	2.161	90.2	160.0	214.3	3	59.2	1	6	0
2901	1.70	1.15	30.04	0.311	70.0	169.8	212.0	3	77.0	1	9	0
2902	2.34	1.62	30.04	0.492	70.0	187.5	212.0	3	77.0	1	9	0
2903	4.55	3.17	30.04	0.751	72.5	173.4	212.0	3	77.0	1	9	0
2904	6.27	4.37	30.04	1.085	73.5	171.5	212.0	3	77.0	1	9	0
2905	8.10	5.70	30.04	1.215	78.0	170.1	212.0	3	77.0	1	9	0
2906	10.85	7.70	30.04	1.815	79.0	167.6	212.0	3	77.0	1	9	0
2907	14.40	10.40	30.04	2.330	84.0	167.0	212.0	3	77.0	1	9	0
2908	17.60	12.75	30.04	2.850	86.3	162.6	212.0	3	77.0	1	9	0
2909	20.20	14.20	30.04	3.110	89.0	163.2	212.0	3	77.0	1	9	0
2911	2.00	1.00	30.45	0.259	68.0	172.0	212.0	3	73.5	1	9	0
2912	3.30	1.90	30.45	0.362	68.7	165.5	212.0	3	73.5	1	9	0
2913	4.20	2.20	30.45	0.647	70.0	163.0	212.0	3	73.5	1	9	0
2914	5.40	2.60	30.45	0.854	70.2	160.0	212.0	3	73.5	1	9	0
2915	6.60	4.15	30.45	0.983	70.6	158.5	212.0	3	73.5	1	9	0
2916	7.80	5.10	30.45	1.100	72.0	157.5	212.0	3	73.5	1	9	0
2917	9.45	6.30	30.45	1.346	73.5	156.0	212.0	3	73.5	1	9	0
2918	11.30	7.10	30.45	1.566	75.2	155.0	212.0	3	73.5	1	9	0
2919	12.75	8.60	30.45	1.812	79.0	155.0	212.0	3	73.5	1	9	0
2920	13.40	10.20	30.45	2.057	79.5	155.0	212.0	3	73.5	1	9	0
2921	14.90	10.85	30.45	2.057	79.5	155.0	212.0	3	73.5	1	9	0
2922	16.00	10.85	30.45	2.277	80.4	154.0	212.0	3	73.5	1	9	0
2923	16.90	11.67	30.45	2.368	81.0	154.0	212.0	3	73.5	1	9	0
2924	17.90	12.12	30.45	2.510	82.3	153.8	212.0	3	73.5	1	9	0
2925	20.10	14.00	30.45	2.834	84.0	154.0	212.0	3	73.5	1	9	0
2926	21.15	14.70	30.45	2.924	84.9	154.0	212.0	3	73.5	1	9	0
2927	23.95	16.70	30.45	3.289	88.0	153.0	212.0	3	73.5	1	9	0
2928	24.35	16.85	30.45	3.351	88.7	153.0	212.0	3	73.5	1	9	0
2929	25.10	17.45	30.45	3.442	88.7	154.0	212.0	3	73.5	1	9	0
2930	27.00	19.00	30.45	3.650	90.5	153.0	212.0	3	73.5	1	9	0
2931	19.20	12.30	30.45	2.640	87.0	156.0	212.0	3	73.5	1	9	0
2932	14.00	8.65	30.45	1.812	84.2	158.5	212.0	3	73.5	1	9	0
2933	8.50	5.00	30.45	1.242	81.0	160.5	212.0	3	73.5	1	9	0
2934	2.35	1.10	30.45	0.233	79.0	175.0	212.0	3	73.5	1	9	0

3301	1.05	0.66	30.03	0.116	69.2	184.9	226.0	3	67.4	0	3	1
3302	1.81	1.11	30.03	0.165	69.9	180.4	222.1	3	67.4	0	3	1
3303	3.00	1.91	30.03	0.210	70.2	177.0	219.2	3	67.4	0	3	1
3304	4.26	2.72	30.03	0.344	71.7	173.4	216.8	3	67.4	0	3	1
3305	5.05	3.27	30.03	0.380	72.3	171.0	214.7	3	67.4	0	3	1
3306	6.02	3.91	30.03	0.458	73.9	171.0	213.8	3	67.4	0	3	1
3307	7.12	4.62	30.03	0.499	74.7	169.0	214.0	3	67.4	0	3	1
3308	8.68	5.66	30.03	0.626	76.0	167.6	211.6	3	67.4	0	3	1
3309	9.63	6.31	30.03	0.683	78.0	170.4	215.9	3	67.4	0	3	1
3310	10.40	6.88	30.03	0.773	78.2	169.5	214.5	3	67.4	0	3	1
3311	11.35	7.44	30.03	0.932	79.2	169.0	213.9	3	67.4	0	3	1
3312	12.35	8.11	30.03	0.978	80.4	168.7	213.1	3	67.4	0	3	1
3313	13.38	8.82	30.03	1.058	81.7	167.9	211.4	3	67.4	0	3	1
3314	14.30	9.44	30.03	1.112	82.5	167.9	211.4	3	67.4	0	3	1
3315	15.78	10.50	30.03	1.219	83.2	167.0	210.8	3	67.4	0	3	1
3316	17.00	11.20	30.03	1.294	84.2	165.0	210.3	3	67.4	0	3	1
3317	18.15	11.99	30.03	1.405	85.3	166.8	210.4	3	67.4	0	3	1
3318	19.95	13.28	30.03	1.524	88.0	166.0	208.9	3	67.4	0	3	1
3319	21.38	14.36	30.03	1.635	88.2	165.8	208.1	3	67.4	0	3	1
3320	23.05	15.35	30.03	1.705	89.5	165.5	207.7	3	67.4	0	3	1
3321	24.13	15.97	30.03	1.809	90.3	165.0	207.2	3	67.4	0	3	1
3322	25.35	16.85	30.03	1.868	91.5	165.0	206.2	3	67.4	0	3	1
3323	26.32	17.55	30.03	1.941	92.7	164.5	205.1	3	67.4	0	3	1
3324	27.65	18.32	30.03	2.068	94.0	165.0	205.1	3	67.4	0	3	1
3325	28.35	18.82	30.03	2.096	94.7	165.0	205.1	3	67.4	0	3	1
3326	29.60	19.50	30.03	2.169	95.5	164.0	206.8	3	67.4	0	3	1
3401	1.00	0.69	30.28	0.197	62.5	178.9	217.5	3	56.4	0	4	1
3402	1.59	1.10	30.28	0.230	63.3	173.1	216.0	3	56.4	0	4	1
3403	2.45	1.69	30.28	0.344	64.2	172.0	215.2	3	56.4	0	4	1
3404	3.78	2.64	30.28	0.551	65.2	168.6	213.7	3	56.4	0	4	1
3405	4.85	3.40	30.28	0.750	67.2	166.8	213.0	3	56.4	0	4	1
3406	5.67	3.96	30.28	0.851	68.1	166.8	213.7	3	56.4	0	4	1
3407	7.08	4.95	30.28	1.134	69.5	165.2	212.2	3	56.4	0	4	1
3408	8.46	5.86	30.28	1.128	71.3	162.8	211.3	3	56.4	0	4	1
3409	9.30	6.50	30.28	1.395	73.0	164.3	213.0	3	56.4	0	4	1
3410	10.55	7.30	30.28	1.563	74.0	163.2	212.4	3	56.4	0	4	1
3411	11.36	7.82	30.28	1.659	74.7	163.0	212.5	3	56.4	0	4	1
3412	12.35	8.58	30.28	1.786	76.2	162.2	212.0	3	56.4	0	4	1
3413	13.27	9.30	30.28	1.928	77.5	162.0	211.7	3	56.4	0	4	1
3414	14.21	9.98	30.28	2.016	79.3	161.2	211.3	3	56.4	0	4	1
3415	15.10	10.60	30.28	2.135	79.3	161.2	211.3	3	56.4	0	4	1
3416	16.15	11.28	30.28	2.270	79.7	161.0	210.7	3	56.4	0	4	1
3417	17.20	11.99	30.28	2.381	80.7	160.9	210.7	3	56.4	0	4	1
3418	18.25	12.85	30.28	2.562	81.7	160.0	210.0	3	56.4	0	4	1
3419	19.48	13.58	30.28	2.681	83.0	160.0	209.8	3	56.4	0	4	1
3420	20.00	13.95	30.28	2.769	83.9	160.2	209.7	3	56.4	0	4	1
3421	21.15	14.82	30.28	2.932	86.7	160.1	209.4	3	56.4	0	4	1
3422	22.50	15.62	30.28	3.064	88.0	160.1	209.4	3	56.4	0	4	1
3423	23.55	16.45	30.28	3.253	90.5	163.0	211.8	3	56.4	0	4	1
3424	24.85	17.32	30.28	3.372	91.0	163.0	211.7	3	56.4	0	4	1
3425	25.40	17.70	30.28	3.442	92.3	163.5	212.0	3	56.4	0	4	1
3426	27.00	18.80	30.28	3.646	93.2	162.0	210.8	3	56.4	0	4	1
3427	28.90	19.73	30.28	3.820	95.2	161.2	209.8	3	56.4	0	4	1
3601	1.10	0.80	30.29	0.181	66.1	165.5	214.5	3	50.5	0	6	1
3602	1.92	0.95	30.29	0.336	66.6	165.8	214.5	3	50.5	0	6	1

3603	3.30	1.90	30.29	0.595	68.0	154.0	214.5	3	50.5	0	6	1
3604	4.32	3.05	30.29	0.673	68.5	161.0	214.5	3	50.5	0	6	1
3605	5.00	3.60	30.29	0.906	69C2	1 9C4	214.5	3	50.5	0	6	1
3606	6.25	4.50	30.29	1.061	70.6	157.5	214.5	3	50.5	0	6	1
3607	7.40	5.15	30.29	1.240	70.7	157.0	214.5	3	50.5	0	6	1
3608	8.35	5.45	30.29	1.361	71.9	155.7	214.5	3	50.5	0	6	1
3609	9.45	6.25	30.29	1.623	72.3	154.2	214.5	3	50.5	0	6	1
3610	10.45	6.70	30.29	1.918	73.1	153.1	214.5	3	50.5	0	6	1
3611	11.65	7.47	30.29	1.993	74.2	152.9	214.5	3	50.5	0	6	1
3612	12.80	8.18	30.29	2.342	75.1	152.6	214.5	3	50.5	0	6	1
3613	14.00	9.80	30.29	2.329	75.8	151.5	214.5	3	50.5	0	6	1
3614	14.45	10.10	30.29	2.383	78.1	155.1	214.5	3	50.5	0	6	1
3615	16.05	11.30	30.29	2.653	78.8	155.2	214.5	3	50.5	0	6	1
3616	17.30	12.20	30.29	2.782	79.6	154.0	214.5	3	50.5	0	6	1
3617	18.20	12.75	30.29	2.878	80.9	153.3	214.5	3	50.5	0	6	1
3618	19.15	13.33	30.29	3.028	83.0	153.1	214.5	3	50.5	0	6	1
3619	20.35	14.51	30.29	3.334	84.1	155.0	214.5	3	50.5	0	6	1
3620	22.70	15.35	30.29	3.434	84.1	153.0	214.5	3	50.5	0	6	1
3621	23.50	16.45	30.29	3.678	85.4	151.0	214.5	3	50.5	0	6	1
3622	27.10	19.10	30.29	4.320	88.6	151.1	214.5	3	50.5	0	6	1
3623	27.90	19.60	30.29	4.334	89.7	149.5	214.5	3	50.5	0	6	1
3624	28.40	19.95	30.29	4.451	90.3	148.3	214.5	3	50.5	0	6	1
3625	20.30	14.70	30.29	3.310	87.4	152.5	214.5	3	50.5	0	6	1
3626	11.00	7.95	30.29	1.874	81.4	153.0	214.5	3	50.5	0	6	1
3901	1.35	0.96	30.39	0.377	64.7	172.5	212.0	3	71.4	0	9	1
3902	1.79	1.25	30.39	0.362	64.7	169.5	212.0	3	71.4	0	9	1
3903	2.50	1.84	30.39	0.538	65.7	171.0	212.0	3	71.4	0	9	1
3904	3.55	2.62	30.39	0.828	66.5	167.0	212.0	3	71.4	0	9	1
3905	4.40	3.31	30.39	1.139	67.2	163.8	212.0	3	71.4	0	9	1
3906	5.35	4.00	30.39	1.294	68.3	162.0	212.0	3	71.4	0	9	1
3907	7.05	5.38	30.39	1.734	71.4	161.0	212.0	3	71.4	0	9	1
3908	7.80	5.88	30.39	1.869	71.9	160.5	212.0	3	71.4	0	9	1
3909	9.50	7.21	30.39	2.252	72.5	159.0	212.0	3	71.4	0	9	1
3910	10.35	7.80	30.39	2.420	73.7	158.8	212.0	3	71.4	0	9	1
3911	11.70	8.60	30.39	2.692	75.0	158.0	212.0	3	71.4	0	9	1
3912	13.90	10.51	30.39	3.219	78.0	158.0	212.0	3	71.4	0	9	1
3913	12.68	9.61	30.39	2.968	78.3	159.5	212.0	3	71.4	0	9	1
3914	14.45	11.00	30.39	3.364	80.0	159.0	212.0	3	71.4	0	9	1
3915	16.00	12.25	30.39	3.670	81.7	158.8	212.0	3	71.4	0	9	1
3916	17.50	13.18	30.39	3.952	83.5	159.2	212.0	3	71.4	0	9	1
3917	16.70	12.68	30.39	3.848	84.2	160.5	212.0	3	71.4	0	9	1
3918	18.60	14.10	30.39	4.322	85.7	159.5	212.0	3	71.4	0	9	1
3919	19.40	14.80	30.39	4.322	87.4	160.0	212.0	3	71.4	0	9	1
3920	20.80	15.70	30.39	4.638	88.0	160.0	212.0	3	71.4	0	9	1
3921	21.50	16.25	30.39	4.814	89.2	160.2	212.0	3	71.4	0	9	1
3922	22.40	16.90	30.39	5.078	90.0	159.7	212.0	3	71.4	0	9	1

4301	0.78	0.48	30.02	0.052	64.2	173.2	225.2	3	64.4	1	3	1
4302	1.70	1.07	30.02	0.101	65.3	174.2	222.2	3	64.4	1	3	1
4303	3.05	1.92	30.02	0.215	65.6	172.0	219.7	3	64.4	1	3	1
4304	4.10	2.64	30.02	0.254	66.7	170.5	218.0	3	64.4	1	3	1
4305	4.80	3.06	30.02	0.311	67.8	169.1	216.6	3	64.4	1	3	1
4306	6.00	3.90	30.02	0.388	69.3	167.5	215.0	3	64.4	1	3	1
4307	7.20	4.62	30.02	0.417	70.0	165.8	214.2	3	64.4	1	3	1
4308	8.10	5.21	30.02	0.468	71.7	167.6	216.0	3	64.4	1	3	1
4309	9.43	6.18	30.02	0.562	72.5	164.7	212.3	3	64.4	1	3	1
4310	10.05	6.87	30.02	0.634	73.9	163.6	210C9	3	64.4	1	3	1
4311	11.32	7.42	30.02	0.709	74.7	162.6	210.3	3	64.4	1	3	1
4312	12.64	8.28	30.02	0.805	76.0	161.8	209.2	3	64.4	1	3	1
4313	13.70	8.98	30.02	0.877	77.3	163.4	211.2	3	64.4	1	3	1
4314	14.35	9.42	30.02	0.929	78.2	163.0	211.4	3	64.4	1	3	1
4315	15.43	10.13	30.02	0.989	79.3	162.6	210.4	3	64.4	1	3	1
4316	16.64	10.09	30.02	1.079	80.5	162.3	211.7	3	64.4	1	3	1
4317	17.62	11.56	30.02	1.123	81.2	162.0	210.4	3	64.4	1	3	1
4318	18.73	12.33	30.02	1.169	82.0	161.7	209.9	3	64.4	1	3	1
4319	19.50	12.90	30.02	1.263	83.0	161.3	209.2	3	64.4	1	3	1
4320	20.95	13.77	30.02	1.294	83.9	161.0	209.9	3	64.4	1	3	1
4321	21.74	14.67	30.02	1.346	84.7	161.0	209.9	3	64.4	1	3	1
4322	22.85	15.08	30.02	1.385	86.0	161.0	208.4	3	64.4	1	3	1
4323	23.25	15.34	30.02	1.429	86.8	161.0	208.3	3	64.4	1	3	1
4324	24.50	16.18	30.02	1.486	87.7	161.2	208.7	3	64.4	1	3	1
4325	25.65	16.85	30.02	1.571	88.4	161.0	207.9	3	64.4	1	3	1
4326	26.85	17.58	30.02	1.630	89.3	161.9	210.0	3	64.4	1	3	1
4327	27.70	18.25	30.02	1.685	90.5	161.7	208.7	3	64.4	1	3	1
4328	28.55	18.83	30.02	1.742	91.3	161.0	207.9	3	64.4	1	3	1
4329	29.45	19.40	30.02	1.783	92.2	160.8	207.2	3	64.4	1	3	1
4401	1.08	0.68	30.34	0.140	68.2	171.0	216.3	3	56.5	1	4	1
4402	1.75	1.14	30.34	0.142	66.3	168.0	214.3	3	56.5	1	4	1
4403	2.66	1.76	30.34	0.230	66.5	166.8	214.2	3	56.5	1	4	1
4404	3.60	2.41	30.34	0.417	66.7	164.5	213.2	3	56.5	1	4	1
4405	4.80	3.24	30.34	0.492	67.3	162.0	212.1	3	56.5	1	4	1
4406	5.85	3.95	30.34	0.546	68.5	160.8	211.7	3	56.5	1	4	1
4407	6.72	4.51	30.34	0.675	69.0	159.4	211.2	3	56.5	1	4	1
4408	8.01	5.36	30.34	0.830	70.2	158.2	210.4	3	56.5	1	4	1
4409	9.50	6.40	30.34	1.108	71.3	158.1	211.1	3	56.5	1	4	1
4410	10.07	6.76	30.34	1.136	72.2	156.9	211.2	3	56.5	1	4	1
4411	11.14	7.54	30.34	1.245	73.0	155.0	208.6	3	56.5	1	4	1
4412	12.37	8.39	30.34	1.364	74.0	155.0	208.7	3	56.5	1	4	1
4413	13.43	9.10	30.34	1.540	75.0	155.0	209.0	3	56.5	1	4	1
4414	14.50	9.81	30.34	1.654	75.3	154.6	208.8	3	56.5	1	4	1
4415	15.00	10.24	30.34	1.708	76.0	153.8	208.0	3	56.5	1	4	1
4416	16.08	10.91	30.34	1.830	76.5	156.0	211.0	3	56.5	1	4	1
4417	17.85	12.20	30.34	1.988	77.0	152.5	207.0	3	56.5	1	4	1
4418	18.95	12.90	30.34	2.120	79.2	154.2	210.6	3	56.5	1	4	1
4419	20.10	13.61	30.34	2.252	80.7	154.0	208.4	3	56.5	1	4	1
4420	21.00	14.25	30.34	2.371	81.7	154.7	209.2	3	56.5	1	4	1
4421	22.20	15.14	30.34	2.500	82.7	154.0	208.8	3	56.5	1	4	1
4422	24.40	17.00	30.34	2.759	85.8	156.0	210.4	3	56.5	1	4	1
4423	25.65	17.55	30.34	2.792	86.7	155.2	209.5	3	56.5	1	4	1
4424	27.30	18.60	30.34	3.043	87.8	154.2	208.1	3	56.5	1	4	1
4425	27.70	19.00	30.34	3.067	88.0	156.0	210.2	3	56.5	1	4	1
4601	1.65	1.05	30.23	0.129	64.7	161.2	216.8	3	59.4	1	6	1

4602	2.70	1.79	30.23	0.313	65.5	161.1	214.8	3	59.4	1	6	1
4603	3.97	2.18	30.23	0.468	66.5	162.0	215.5	3	59.4	1	6	1
4604	5.35	3.67	30.23	0.652	67.0	159.9	214.0	3	59.4	1	6	1
4605	6.60	4.47	30.23	0.831	68.6	159.0	213.1	3	59.4	1	6	1
4606	7.55	5.12	30.23	0.947	69.8	158.1	214.2	3	59.4	1	6	1
4607	8.65	5.80	30.23	1.136	71.0	157.5	213.8	3	59.4	1	6	1
4608	9.68	6.56	30.23	1.281	71.9	156.6	213.3	3	59.4	1	6	1
4609	10.98	7.45	30.23	1.454	72.9	156.0	212.6	3	59.4	1	6	1
4610	12.30	8.40	30.23	1.602	74.6	155.5	212.0	3	59.4	1	6	1
4611	13.85	9.50	30.23	1.814	76.0	155.0	212.8	3	59.4	1	6	1
4612	14.82	10.11	30.23	1.969	77.2	154.9	211.3	3	59.4	1	6	1
4613	16.10	11.03	30.23	2.145	79.0	154.9	211.3	3	59.4	1	6	1
4614	17.30	11.80	30.23	2.265	80.5	154.8	210.9	3	59.4	1	6	1
4615	18.10	12.37	30.23	2.363	81.5	154.7	210.8	3	59.4	1	6	1
4616	19.35	13.24	30.23	2.505	82.0	154.3	210.6	3	59.4	1	6	1
4617	20.65	14.12	30.23	2.689	83.2	154.0	210.2	3	59.4	1	6	1
4618	21.50	14.70	30.23	2.712	83.8	154.0	209.6	3	59.4	1	6	1
4619	22.10	15.10	30.23	2.772	83.9	153.9	209.6	3	59.4	1	6	1
4620	23.15	15.62	30.23	2.875	85.5	153.0	208.7	3	59.4	1	6	1
4621	25.25	17.40	30.23	3.186	86.2	154.0	209.3	3	59.4	1	6	1
4622	27.20	18.75	30.23	3.416	90.0	153.0	207.6	3	59.4	1	6	1
4623	21.60	14.70	30.23	2.759	88.3	157.0	211.2	3	59.4	1	6	1
4624	14.14	9.63	30.23	1.824	83.5	160.0	212.6	3	59.4	1	6	1
4625	9.50	6.44	30.23	1.245	81.0	162.0	215.4	3	59.4	1	6	1
4626	4.62	3.06	30.23	0.631	77.0	168.0	219.0	3	59.4	1	6	1
4901	1.90	1.45	30.44	0.453	62.0	160.8	212.0	3	58.8	1	9	1
4902	2.60	1.96	30.44	0.525	63.0	156.0	212.0	3	58.8	1	9	1
4903	3.70	2.78	30.44	0.828	63.9	154.5	212.0	3	58.8	1	9	1
4904	4.90	3.70	30.44	1.074	64.7	152.0	212.0	3	58.8	1	9	1
4905	5.70	4.32	30.44	1.216	66.0	152.0	212.0	3	58.8	1	9	1
4906	7.30	5.50	30.44	1.524	67.0	150.5	212.0	3	58.8	1	9	1
4907	8.30	6.20	30.44	1.643	69.0	151.0	212.0	3	58.8	1	9	1
4908	10.15	7.60	30.44	2.070	69.6	150.0	212.0	3	58.8	1	9	1
4909	11.20	8.48	30.44	2.324	71.1	149.0	212.0	3	58.8	1	9	1
4911	13.40	10.10	30.44	2.722	72.1	148.0	212.0	3	58.8	1	9	1
4910	12.20	9.15	30.44	2.477	72.2	148.8	212.0	3	58.8	1	9	1
4912	14.29	10.68	30.44	2.852	73.7	248.0	212.0	3	58.8	1	9	1
4913	15.10	11.32	30.44	3.082	74.7	150.0	212.0	3	58.8	1	9	1
4914	16.72	12.50	30.44	3.331	76.7	150.0	212.0	3	58.8	1	9	1
4915	17.70	13.20	30.44	3.494	79.2	150.0	212.0	3	58.8	1	9	1
4916	18.85	13.37	30.44	3.817	81.5	150.0	212.0	3	58.8	1	9	1
4917	22.75	17.13	30.44	4.477	82.5	149.0	212.0	3	58.8	1	9	1
4918	24.00	18.00	30.44	4.620	84.2	148.5	212.0	3	58.8	1	9	1
4919	25.40	18.90	30.44	4.917	86.4	148.0	212.0	3	58.8	1	9	1
4920	20.10	15.27	30.44	3.960	85.6	150.5	212.0	3	58.8	1	9	1
4921	19.70	15.00	30.44	3.929	85.5	250.5	212.0	3	58.8	1	9	1
4922	18.45	13.92	30.44	3.610	84.9	151.0	212.0	3	58.8	1	9	1
4923	15.60	12.00	30.44	3.178	83.6	153.6	212.0	3	58.8	1	9	1
4924	12.30	9.37	30.44	2.420	80.2	156.0	212.0	3	58.8	1	9	1
4925	7.50	5.75	30.44	1.566	76.7	158.0	2 2.0	3	58.8	1	9	1
4926	4.75	3.70	30.44	1.035	74.8	162.0	2 2.0	3	58.8	1	9	1

APPENDIX F

Reduced Experimental Data

This Appendix consists of a listing of the results of the data reduction. The column headings are self explanatory.

RUN CODE	EXP NUSSELT	GRIM NUSSELT	CAL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
401	15. 3 6	23.1121	5.981	.65 334	1423.51	. 6 334	1451.94
402	26.3 24	34.5522	1 .51 8	.76181	2878.69	. 5 267	295 .47
403	16. 758	24.4627	6.4 3	.6 7156	1569.69	. 59888	16 2.63
404	16.6895	24.4669	6.4078	.692124	1568.3	. 48519	1599.67
405	15.1461	25.6914	6.9 16	.589538	1769.14	. 67599	1752.32
406	14.5237	25.7 74	6.9	.567489	171 .16	. 56 18	1754.81
407	19.4752	27.3328	7.54 7	.712521	1901.61	. 4 6	1941.
408	31. 43	39.4738	12.8617	.777867	3712.11	. 43789	381 .54
409	16.9219	28. 1 9	7.8 28	.6 4118	1985.35	. 4 872	2 37.13
410	17.7626	28.28 1	7.9 43	.628833	2 15.2	. 53776	2 63.67
411	17.5491	28.5974	8. 3 2	.613669	2 57.	. 3875	211 .9
412	19. 81	29.6569	9.4489	.64 62	2192.91	. 412 8	2 49.24
413	25.2171	31. 325	8.9 33	.8126 1	369.64	. 44785	2417. 4
414	2 .6762	31.6421	9.2 98	.6 5 9	2442.49	. 43672	25 6.11
415	2 .9436	31.7678	9.3 13	.659272	471.99	. 4341	2576.38
416	4 .6698	46.384	15.9741	.677238	4857.64	. 41894	4986.45
417	22.1565	33.1758	9.8672	.667851	2669. 9	. 4 165	2739.71
418	22. 136	33.18 8	9.8881	.663444	2668.47	. 4 82	27 8. 1
419	25.1295	34.5939	1 .4887	.72 415	2873. 7	. 465 8	2945.8
420	26.9 13	35.4 62	1 .8345	.76 356	2988.84	. 49 7	3 9.40
421	24.3577	35.9280	11. 652	.677943	3 71.30	. 76783	3154.84
422	29.5547	37.7497	11.8677	.722912	3349.27	. 425 4	3429.
423	46.7712	55.3315	2 .7 37	.84 292	6725.72	. 4283	6912.
424	5.7182	38.4672	12.1946	.665574	3468. 1	. 41466	3566.1
425	4 .4139	55.6469	2 .9 2	.87 18	6797.34	. 43892	6987.2
426	28.6134	4 . 5	12.8984	.715245	3719.93	. 52429	382 .14
427	31.9617	41.9328	1 .7973	.762213	4 43.38	. 46966	4146.62
428	33.4724	43. 318	14.5687	.768918	4331.53	. 45578	4445.9
429	35.6292	45.965	15.7 2	.77 137	4775.38	. 45357	49 2.71
430	34.9426	46. 244	15.7366	.7 9219	4792.58	. 463 2	4922.17
431	36.2 3	47.6997	16.644	.758977	5116. 6	. 4 811	5255.92
432	38.6195	49. 757	17.3532	.786937	389.96	. 461 5	5534.9
433	4 .4421	51.1512	18.45 9	.79 484	5819.47	. 46675	5977.68
434	4 .36 7	52. 298	18.91	.779722	5995.99	. 45997	6163.79
435	41.6839	53.8 26	19.88 3	.774757	388.4	. 44311	6565.6
436	42.8086	55.582	2 .8678	.771268	6787.48	. 45962	6977.55
601	15.27	21.5762	5.444	.7 7723	1266.45	.154549	1294.98
602	15.9273	24. 75	6.3236	.661 76	1528.72	.214625	1567.73
603	2 .5317	27.6745	7.6736	.741896	1945.17	.165432	1993.9
604	21.2737	28.5 56	7.9982	.746299	2 5 .1	.319 32	21 . 4
605	23.1144	29.624	8.4368	.78 259	2189.86	.209 45	2244.72
606	25. 564	31.5 74	9.1367	.795253	2439.11	.189932	25 1.
607	25.8439	33.3341	9.955	.77 298	2693. 5	.208818	2764.54
608	27.7272	35. 904	1 .7 37	.79 165	2948.59	.2 3873	3 28.
609	28.79 4	35.67 4	1 .9582	.8 7121	3 38.88	.253172	3117.58
610	28.7491	36.6453	11.3828	.784524	3184.25	.213217	3272.47
611	.1474	36.8727	11.4364	.8176 7	3223.1	.249876	33 8. 3
612	31.6063	38. 919	12. 314	.831839	3415.36	.2543 3	35 5.12
613	31.27 4	38.4197	12.1762	.814047	3464. 7	.18 5 7	356 . 3
614	3 .7378	39.769	12.7927	.7729	3684.71	.235711	379 .32
615	34.4392	4 .3776	13. 782	.852979	379 .77	.241899	3891.85
616	36.7285	42. 451	13.8627	.873548	4 77. 9	.239198	4185.51
617	34.4845	42.1154	13.8922	.81881	4 84.69	.222139	4199.97
618	33.7838	43. 753	14.3 2	.784296	4254.38	.283866	4376.8

UN (DE	EXP NUSSELT	GRIM NUSSELT	COL NUSSELT	F THETA	REYNOLDS	FRICTION	REYNOLDS(F)
119	37.8975	43.2855	14.4576	0.875524	4296.97	0.243446	4412.84
120	39.0731	44.7607	15.1777	.872934	4566.17	0.252227	4690.65
121	36.9713	45.2897	15.4095	0.816329	4664.86	0.237223	4799.10
122	40.5286	46.2872	15.9376	0.875591	4853.72	0.241094	4991.32
123	41.7769	47.3001	16.4498	0.833232	5049.48	0.248017	5191.19
124	43.0647	47.7718	16.6905	0.901468	5141.99	0.238733	5284.04
125	39.5397	47.8078	16.7090	.827056	5149.17	0.259403	5298.70
126	41.9676	49.0156	17.3321	.856210	5390.23	0.248410	5541.63
127	47.0441	50.1262	17.9133	0.938512	5617.13	0.237532	5772.30
128	44.8080	50.8228	18.2762	.881652	5755.09	0.240122	5919.72
129	46.1010	51.3273	18.5506	0.899151	5868.02	0.240767	6033.35
130	46.6691	52.2394	19.0347	0.893369	6055.17	0.249740	6227.06
131	46.9086	52.4051	19.1302	0.895116	6098.09	0.241352	6272.02
101	16.0622	22.1285	5.6377	.726763	1324.38	0.276980	1357.14
102	19.3492	26.3881	7.1858	.733253	1793.65	0.229071	1342.44
103	23.0312	29.6327	8.4431	.777222	2194.14	0.306599	2254.54
104	25.7534	31.7267	9.2897	.811725	2472.53	0.301927	2540.43
105	28.1032	33.8774	10.1880	.829556	2774.91	0.321462	2851.98
106	30.6154	35.5585	10.9103	.860989	3022.97	0.324512	3106.93
107	31.7864	36.9607	11.5025	0.861256	3229.47	0.296820	3320.15
108	34.7015	38.5067	12.2198	0.901181	3483.12	0.295808	3579.36
109	34.7016	39.6099	12.7039	.875589	3663.65	0.314605	3767.33
110	36.8669	41.1567	13.4445	0.895726	3924.80	0.315410	4035.56
111	37.8065	42.9489	14.2963	0.880257	4238.06	0.299457	4360.37
112	39.6792	44.6344	15.1168	0.888982	4544.27	0.292021	4677.01
113	41.8645	46.0173	15.9037	0.905818	4841.84	0.295489	4982.86
114	43.6006	47.5138	16.5610	0.917601	5093.25	0.291977	5241.16
115	45.2862	48.7803	17.2114	.928411	5344.49	0.301136	5499.22
116	48.0465	50.6569	18.1952	0.948470	5729.04	0.301860	5894.41
117	50.8769	52.5483	19.2093	.968193	6130.88	0.301863	6307.30
118	51.6957	53.6260	19.7571	0.964003	6366.23	0.305462	6548.20
101	25.9762	28.2556	7.8960	.919328	2013.55	0.094386	2061.17
102	43.0736	45.1094	15.3393	.954870	4618.16	.102521	4746.65
103	51.3770	52.4296	19.1293	.979923	6086.09	0.097796	6263.28
104	35.3091	39.2984	12.5716	.898488	3601.22	0.292767	3700.98
105	59.6198	59.2900	22.9057	1.005562	7657.64	0.098460	7886.62
106	44.7365	45.9920	15.7782	.972685	4783.48	0.224745	4914.41
107	52.2875	52.8640	19.3648	0.985715	6179.79	0.177695	6353.31
101	83.8333	73.5113	31.8301	1.140414	11516.56	0.099961	11801.24
102	74.4320	69.9663	29.5397	1.063826	10492.66	0.012070	10801.54
103	70.0767	67.0410	26.0661	1.036009	9843.48	0.013648	10142.83
104	57.0724	56.098	21.4516	1.008381	7034.96	0.026499	7260.37
105	70.2382	69.4146	29.1805	1.011865	10327.37	0.012090	10651.31
106	69.5325	66.9257	27.6072	1.038951	9633.89	0.013959	9922.85
107	70.4534	63.9935	25.7943	1.100945	8847.63	0.016048	9098.60
108	57.0880	54.6083	20.3282	1.045409	6571.33	0.029570	6768.31
109	51.8007	51.3121	18.5348	1.009522	5855.43	0.036099	6074.62
110	48.3818	49.5316	17.5950	.976785	5487.46	0.041946	5660.53
111	41.9190	45.0065	15.3228	.930169	4616.46	0.057999	4760.85
112	65.5399	69.9718	29.5324	.936662	10480.17	0.103784	10798.15
113	63.0772	66.7242	27.4806	.945342	9578.11	0.103547	9869.99
114	59.3965	61.7051	24.4154	.962587	8261.90	0.116918	8515.15
115	60.3328	59.6811	23.2190	1.010919	7758.96	0.107863	7991.80
116	49.2657	49.5285	17.5013	.994696	5484.30	0.109127	5644.03

UN DE	EXP NUSSELT	CRIM NUSSELT	CAL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
117	46. 8	47.512	16.6 11	0.967210	5131.20	0.113554	5249.9
118	32.1739	35.4792	1 .848	.958631	2994.21	0.1199 1	3 72.9
119	1 .4489	73.2116	31.6167	1.37 36	114 4.65	0. 28792	11719.61
12	89.1163	66.5838	27.365	1.3384 9	9529.65	0. 32619	9789.86
121	76.8976	58.6893	22.75 8	1.3 798	7558.38	0. 31396	7753.57
122	7 .7996	52.9996	19.4381	1.335851	6208.69	0. 32624	6362.6
123	57. 740	44.5613	15. 83	1.28 825	4516.06	0. 32922	4619.95
124	4 . 1	35.7949	11.5 51	1.11897	3 49.11	0. 4 417	3117.43
201	12.3949	2 .8852	6.7678	0.593477	1662.94	0. 17360	1715.94
202	14.5245	22.937	7.6503	.633235	1940.93	0. 1616	2 2.55
203	19. 688	28.1698	10. 414	.67 9 4	2722.07	0. 142 4	28 9.32
204	21.1338	3 .8471	11.315	.685114	3160.66	0. 6597	3266.83
205	22.5685	32.5652	12.1498	0.693 25	3454.57	0. 13324	3569. 1
206	25.1769	35.5678	13.6399	0.7 7856	3991.65	0. 17155	4124.54
207	25.1 18	36.6477	14.1851	.717874	4191.96	0. 22721	4328.88
208	28.8192	39.3132	15.5514	0.733 66	4782.47	0. 27226	4855.75
209	29.7656	40.8141	16.3329	0.729297	4999.52	0. 32145	5161. 4
21	31.7723	43.4157	17.7 76	0.731839	553 .54	.135428	57 8.7
211	33.0387	44.9229	18.5153	.735454	5847.36	0. 38668	6030.98
212	33. 226	45.4 11	18.7741	.727352	595 .63	. 39319	6141.
213	3 .6950	42.5813	17.2652	.72 836	536 .16	. 364 3	5541.79
214	27.2367	38.2307	15.3 32	0.7 1423	461 .38	. 37852	4767.48
215	32.2694	41.7579	16.8311	.772775	5193.78	. 38336	5375.84
16	18.5182	26.845	9.4253	.689819	2515.89	0. 19846	2593.13
01	21.9638	20.2273	6.4857	1. 8 85	1575.12	0.156421	1627.47
02	37.1 2	22.2729	7.3355	1.67 963	1837.11	.17621	1876.96
203	37.8691	27.1838	9.5796	1.393 79	2564.74	.141876	2644.12
04	42.4945	29.9465	1 .8 7	1.419 14	3 7.32	.149856	31 3.47
05	45.5653	32.33 6	12. 328	1.4 9354	341 .47	0.130577	352 .32
206	49.6921	35.3113	13.5 89	1.4 7258	3941.25	0.147229	4 73.7
207	54.3514	38.4134	15.0847	1.4149 6	4524.05	.143718	4675.2
208	53.6 45	4 .816	16.3264	1.31364	4994.24	.145737	517 .66
209	56.6977	42.4947	17.2158	1.334229	5336.57	0.139198	5521.86
01	12.5 45	19. 841	6.0 81	.65 23	1433.95	0. 43582	1491.2
202	14.1787	21.0333	6.8326	0.6741 8	1684. 8	0. 52453	1753.85
203	17.736	24. 889	8.1722	.736273	21 6. 4	0. 87678	2191.33
04	19.8547	26.3172	9.1835	.754437	2436.42	0.080761	2536.23
205	21.9980	28.1119	1 .0163	.782518	2715.87	0. 88252	2827.49
206	23.9 86	29.8256	10.827	.8 1614	2993.17	0. 85592	3115.56
207	25.3819	31.2212	11.4575	0.812968	3226.51	0. 8 18	3358.39
208	27. 420	32.7753	12.2547	0.825072	3494.00	0. 78558	3636.7
209	26.5780	33.6657	12.6939	0.789468	3651.81	0. 78577	38 8.85
21	28.8387	34.9992	13.3567	0.823984	3890.67	0. 845 5	4 49.72
11	29.9118	35.42 7	13.5688	0.844473	3968.95	0. 84268	4134.48
212	30.8435	36.6714	14.1995	0.841076	42 . 1	0.084376	4372.32
213	31.5969	37.6349	14.6951	0.839564	4382. 5	0. 82837	4562.42
214	32.2 91	38.4931	15.1304	0.835751	4546.88	0. 82471	4735.21
215	33.5745	39.21 6	15.5 8	0.856259	4686.36	0.080625	4878.78
216	34.1433	39.8184	15.8159	0.8574 1	4805.60	0. 82262	5 2.31
217	34.3496	40.9047	16.3830	0.839746	5022. 4	0. 82724	5230.54
218	36.1264	41.7222	16.8126	0.865879	5187.14	0. 83978	5399.17
219	36.1394	42. 463	16.9837	0.859513	5253.13	0. 84688	5466.09
220	37.2820	42.7771	17.3767	.871543	54 3.55	0.082341	5620.78
221	37.0 83	43.7282	17.8774	.860047	5600.63	0. 82224	5826.34

RUN CODE	EXP NUSSELT	GRIM NUSSELT	CUL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
222	38.2712	44.3077	18.1577	0.863760	5722.39	0.081986	5951.81
223	39.2178	45.0467	18.5851	0.870448	5878.87	0.080808	6111.43
224	39.1197	45.4031	18.7776	0.861610	5955.19	0.081348	6191.16
225	40.3458	46.1322	19.1726	.868067	6112.33	0.081239	6351.82
226	40.9551	46.7074	19.4856	.875773	6236.80	0.080714	6479.86
227	41.1337	47.2313	19.7716	.871898	6351.20	0.081113	6595.42
228	41.2472	47.5567	19.9225	.868241	6412.02	0.081164	6659.26
201	13.9516	18.8668	5.9169	.739476	1406.01	0.132015	1464.24
202	17.9[illegible]1	22.1138	7.2988	0.8[illegible]9455	1827.64	0.116778	1902.66
203	20.7093	24.5011	8.3560	.848919	2164.27	0.093719	2253.19
204	22.7708	26.1720	9.1152	.870043	2412.75	0.088779	2512.36
205	24.9534	27.9930	9.9594	0.891414	2695.27	0.092371	2806.94
206	27.8683	29.9978	10.9081	.920011	3019.89	0.094485	3144.12
207	29.4520	31.6659	11.7117	.930087	3300.22	0.100749	3435.56
208	31.4014	33.2561	12.4899	0.944832	3576.61	0.106680	3722.66
209	33.3439	34.5243	13.1166	.965809	3803.14	0.107152	3957.89
210	34.7394	36.1277	13.9231	.961570	4096.67	0.104625	4263.02
211	35.3225	36.9520	14.3409	.955903	4251.14	0.105871	4425.51
212	36.4066	37.5342	14.6373	0.970491	4360.76	0.103556	4535.43
213	37.2062	38.2748	15.0167	.972081	4502.45	0.104809	4682.13
214	38.8154	39.3048	15.5481	.987549	4702.49	0.106246	4887.88
215	39.5830	40.1960	16.0110	.984752	4878.18	0.104136	5069.64
216	40.1787	40.9796	16.4256	0.980456	5034.33	0.103426	5229.90
217	40.9655	41.1430	16.5065	0.996173	5067.54	0.105713	5262.39
218	42.2888	42.3214	17.1273	0.999254	5307.10	0.104223	5509.85
219	41.2094	42.5439	17.2457	.970748	5352.94	0.104571	5558.34
220	43.1819	43.5610	17.7867	0.991254	5563.58	0.103077	5771.77
221	44.3342	43.7951	17.9119	1.0[illegible]	5612.66	0.103026	5823.93
222	44.7048	44.7557	18.4270	0.999980	5814.78	0.103980	6031.59
223	45.0037	45.2430	18.6898	0.995814	5918.59	0.102842	6138.86
224	45.8192	45.7303	18.9531	1.001943	6022.74	0.102689	6243.11
225	47.5843	47.0759	19.6828	1.0[illegible]	6314.17	0.102287	6541.89
226	42.2617	41.0443	16.7180	1.017267	5149.58	0.1047[illegible]	5341.67
2[illegible]1	25.1268	21.2382	6.9179	1.183096	17[illegible]7.68	0.112105	1762.54
2[illegible]2	28.3653	24.7219	8.4537	1.147374	2194.09	0.096135	2272.49
2[illegible]3	30.2377	26.5916	9.3[illegible]2	1.137114	2474.09	0.135610	2565.46
2[illegible]4	32.3192	28.6983	10.2087	1.126174	2804.80	0.140082	2912.65
2[illegible]5	34.5956	30.4933	11.1432	1.134529	3098.94	0.132848	322[illegible].2[illegible]
2[illegible]6	36.4714	32.065[illegible]	11.9[illegible]7	1.137421	3365.55	0.126333	3498.44
2[illegible]7	38.4854	33.9717	12.8414	1.132867	3706.14	0.128353	3848.24
2[illegible]8	40.6280	35.8435	13.7772	1.133482	4040.20	0.125448	4202.96
2[illegible]9	42.1768	37.1511	14.4396	1.135275	4284.41	.129163	4455.63
2[illegible]	42.7138	37.7011	14.7[illegible]2	1.132959	4388.75	0.126487	4563.39
2[illegible]1	44.7911	38.0165	15.3448	1.150953	4622.72	0.126164	4806.37
2[illegible]2	45.0524	39.7562	15.7797	1.133216	4787.08	0.130504	4978.85
2[illegible]3	46.0100	40.4085	16.1194	1.138622	4916.23	0.128845	5112.79
2[illegible]4	46.5280	41.1011	16.4818	1.132039	5054.78	0.129164	5256.43
2[illegible]5	48.6121	42.5345	17.2278	1.142887	5346.20	0.130645	5557.75
2[illegible]6	49.3766	43.1782	17.5798	1.143554	5479.10	0.128409	5695.22
2[illegible]7	49.6308	44.7895	18.4421	1.1[illegible]8101	5817.08	0.128474	6046.51
2[illegible]8	49.6401	45.0044	18.5581	1.1[illegible]30[illegible]7	5862.83	0.128799	6093.48
2[illegible]9	51.5299	45.4035	18.7736	1.134929	5948.05	0.128512	6179.5[illegible]
2[illegible]	51.1219*	46.3904	19.3087	1.1[illegible]1993	6160.69	0.127418	6401.45
2[illegible]1	48.1519	41.9201	16.9128	1.148561	5220.44	0.126285	5420.24

RN DE	EXP NUSSELT	GRIM NUSSELT	CUL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
92	44.7421	38.1419	14.946	1.173044	4472.95	.116969	4641.73
93	37.5303	32.8373	12.2815	1.142917	3499.50	0.129907	3628.84
94	27.0874	22.2423	7.3530	1.217836	1842.94	0.085130	1897.33
1	9.3956	19.9211	4.9662	0.471613	1224.39	0.091222	1252.35
2	11.9564	23.3532	6.1857	0.511981	1610.81	0.075923	1648.01
3	15.0284	27.0137	7.5789	0.556031	2076.19	0.058801	2124.56
4	17.1478	29.8576	8.7264	0.574151	2476.02	0.068360	2534.89
5	18.2911	31.3460	9.3494	0.583522	2698.68	0.064033	2763.06
6	20.0108	32.9187	10.0247	0.607887	2944.37	0.064904	3013.18
7	20.7492	34.4865	10.7154	0.6[illegible]165	3200.14	0.065090	3277.93
8	22.8319	36.4465	11.6027	0.626449	3534.31	0.062208	3618.31
9	23.5746	37.4094	12.0495	0.630178	3705.95	0.061079	3796.39
10	24.5034	38.2234	12.4312	0.640981	3853.06	0.064234	3946.11
11	25.3640	39.1448	12.8692	0.647954	4023.38	0.071162	4120.12
12	26.3573	40.0530	13.3067	0.658060	4194.89	0.068823	4294.53
13	27.3839	40.9464	13.7425	0.668773	4366.95	0.068967	4468.50
14	28.1259	41.6775	14.1035	0.674847	4510.82	0.067981	4615.59
15	29.0685	42.7979	14.6639	0.679204	4735.84	0.067880	4846.18
16	28.8828	43.6677	15.1050	0.661421	4914.44	0.067207	5031.63
17	30.6770	44.4101	15.4856	0.690766	5069.72	0.068422	5186.79
18	31.5940	45.5423	15.0730	0.693727	5310.83	0.067867	5430.92
19	32.8778	46.3910	16.5191	0.708712	5495.49	0.068254	5618.23
20	33.7121	47.3122	17.0089	.712546	5699.83	0.066295	5826.42
21	34.1086	47.8867	17.3172	0.712276	5829.17	0.067392	5958.21
22	35.1173	48.5132	17.6557	0.723872	5971.57	0.066453	6100.83
23	35.5867	49.0018	17.9214	0.726232	6083.79	0.066702	6213.39
24	36.4539	49.6178	18.2590	0.734694	6227.35	0.067805	6358.29
25	36.6609	49.9342	18.4333	.734184	6301.76	0.067139	6474.01
26	35.2844	50.4650	18.7279	0.699186	6428.41	0.066752	6570.18
1	13.5717	19.7353	4.9029	0.687684	1205.15	0.165711	1231.37
2	15.6506	22.5919	5.9083	0.692751	1521.52	0.122803	1557.81
3	19.1399	25.5748	7.0207	0.748388	1887.58	0.119736	1932.8
4	22.6477	28.9432	8.3524	.782485	2345.11	0.125339	2403.22
5	24.7276	31.0459	9.2240	0.796484	2654.84	0.133594	2721.67
6	26.3177	32.4143	9.8081	0.811917	2866.71	0.129938	2939.67
7	28.8314	34.4895	10.7126	.835949	3202.89	0.139465	3284.23
8	30.0763	36.2341	11.5074	0.830057	3500.06	0.116782	3590.78
9	31.3282	37.1425	11.9271	0.843458	3660.59	0.131391	3755.58
10	32.6674	38.4476	12.5395	0.849660	3896.93	0.130337	3998.58
11	33.5312	39.2213	12.9083	0.854923	4040.73	0.128758	4146.47
12	34.2386	40.1186	13.3412	.853434	4210.71	0.127921	4320.96
13	35.1179	40.8988	13.7221	0.858653	4361.46	0.128845	4475.1
14	35.9272	41.6571	14.0965	0.862450	4510.65	0.126182	4628.31
15	36.4919	42.3374	14.4357	0.861930	4646.68	0.126069	4767.9
16	37.7433	43.1101	14.8249	.875508	4803.06	0.125713	4928.07
17	38.5266	43.8313	15.1919	.878976	4952.76	0.124135	5080.83
18	38.9670	44.5346	15.5032	0.874982	5100.24	0.126373	5232.06
19	39.8876	45.3019	15.9513	.880483	5263.88	0.124223	5399.01
20	40.3126	45.6112	16.1128	0.883832	5330.57	0.125078	5466.40
21	40.4754	46.2720	16.4603	0.874727	5474.51	0.125518	5612.53
22	41.2100	47.0187	16.8565	0.876460	5639.71	0.123656	5781.38
23	42.4375	47.5004	17.1167	.893345	5749.30	0.125273	5892.2
24	43.4164	48.1718	17.4763	.901282	5900.67	0.123480	6046.89
25	43.5213	48.4253	17.6138	0.898731	5958.86	0.123355	6106.1

UN DE	EXP NUSSELT	GRIM NUSSELT	COL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
326	43.8116	49.2273	18.05 6	0.889965	6143.74	0.123629	6295. 1
327	44.1715	50.1085	18.5354	0.881518	635 .39	0.121548	65 5.06
301	13.95 1	25.3381	5.11 4	.68591	1269.47	0.14 337	13 3. 8
302	18.4479	23.8758	6.3780	.772822	1674.58	0.14962	1718.66
303	23.1553	27.8490	7.9119	0.831458	2192.30	0.155154	2251.52
304	24.9671	30. 547	8.8123	.83 723	2537.80	0.135 39	2573.58
305	25.9351	31.3137	9.3385	.828234	2697.13	0.157641	2774.86
306	27.6696	33.3258	10.2 35	0.83 4	3 12.94	0.148462	31 1.72
307	29.7783	34.9136	1 .91 1	.852928	3275.97	0.147 89	3373.11
308	3 .5516	36.0915	11.4441	0.8465 5	3477.60	0.14346	3582.13
309	31.4599	37.3392	12. 24	.842542	3697.88	0.151866	381 .98
310	32.1483	38.3765	12.5 78	0.8377 8	3886.26	0.162791	4 6.43
311	33.4581	39.5171	13.0524	.846674	4 98.93	0.15220	4225.6
312	34.5 7	40.5286	13.5431	0.852656	4292.43	0.163278	4425.23
313	35.1 91	41.518	14.0 3	.845636	4486.16	.149349	4626.46
314	37.4993	41.8328	14.1863	0.8964 9	4548.66	0.147592	4684.19
315	39.3 71	43. 159	14.7	.913779	4787.85	0.148594	493 . 6
316	39.5 3	43.884	15.2 18	.9 169	4967.42	0.145194	5116.76
317	39.4179	44.473	15.5245	.886332	5 91.21	0.143116	5244.97
318	39.3995	45.0615	15.8293	.874350	5216.44	0.143339	5373.38
319	41.7775	45.7677	16.1983	0.912816	5368.81	0.148816	5526.29
320	42.2261	47.1117	16.9 98	.896298	5665.23	0.138330	5835.31
321	4 .55 4	47.5453	17.142	.852879	5762.65	0.143768	5938.84
322	41.9721	49.3156	18.1 27	.851090	6169. 8	0.147711	6355.5
323	4 .4814	49.5921	18.3 96	.814645	6257.37	0.144355	6449.1
324	39.3 4	49.9253	18.4383	0.788985	6312.41	0.145945	6507.87
325	38.1674	45.7328	16.18	.834572	5361.22	0.148226	5521.45
326	3 .4463	38.8647	12.7397	0.783394	3976.45	0.151 19	4 96.78
3 1	21.243	21.595	5.5491	0.983597	1405.45	0.237798	1436.56
3 2	23.1 46	23.4317	6.2129	0.986084	1618.67	0.173112	1656.83
3 3	27.9 6	25.7662	7. 922	1. 82839	1909.98	0.184419	1953.51
3 4	3 .6662	28.4723	8.1591	1.077056	2275.58	0.201442	2331.68
3 5	32. 3	3 .2555	8.8923	1.057666	2533.31	0.224933	2599.25
3 6	33.8456	31.9574	9.6 97	1. 9085	2791.82	0.211 8	2866.44
3 7	37.25 6	34.4855	1 .714	1. 8 18	3198.73	0.215831	3284.92
3 8	38.6461	35.4585	11.1512	1.069897	3362.73	0.210798	3453.97
3 9	41.2 47	37.4292	12.0572	1.1 869	3707.64	0.2 9946	381 .32
3	42.42 5	38.3 59	12.469	1.1 7413	3866.59	0.207528	3973.66
3 1	43.9 55	39.5953	13. 847	1.1 6841	4136.69	0.204999	4221.32
3 2	46.51 3	41.455	13.9 2	1.124371	4465.37	0.2 7552	4589.59
3 3	45.8 18	4 .4337	13.4 8	1.132762	4266.59	0.208679	4382.26
3 4	47.6 83	41.8685	14.1 77	1.138277	4547.85	0.208631	4671.47
3 5	49.16 1	43. 125	14.7716	1.142927	4778.76	0.2 6435	4908.44
3 6	5 .9676	44. 334	15.2914	1.157476	4989.84	0.203816	5123.85
3 7	5 .8760	43.4769	15. 71	1.17 183	4874.14	0.2 7185	5 2.42
3 8	51.7896	44.7323	15.6514	1.157767	5137. 8	0.21 165	5273.64
3 9	52.5533	45.2171	15.9 3	1.163128	524 .5	0.2 1763	5378.19
3	54.1 10	46. 495	16.3369	1.174843	542 .66	0.202656	5562.84
1	54.5874	46.4415	16.5458	1.1754 3	5506.56	0.203773	565 . 9
3 2	54.6417	46.9459	16.81 9	1.164 51	5617. 6	0.216859	5764.15
1	5.8721	17.4163	4.4296	0.394582	1 61.48	0. 56633	11 3.77
2	1 .6292	21.9654	6.3468	0.483916	1566. 4	0. 50632	1624.60
3	14.1 53	26.146	7.6426	.539482	2098.43	0. 6 535	2176.23
4	16.1616	28. 566	8.6 39	0.566 68	2433.22	0. 5346	2522.71

RUN CODE	EXP NUSSELT	GRIM NUSSELT	CCL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
405	17.2431	29.9240	9.1665	0.576229	2633.50	0.056002	2729.91
406	18.9261	31.9712	10.0227	0.591969	2944.29	0.056265	3051.4
407	20.1921	33.7415	10.7798	0.598434	3224.76	0.050651	3343.25
408	21.3638	34.8796	11.2746	0.612640	3411.16	0.050518	3536.27
409	22.7895	36.5253	12.0[illegible]4	.623936	3687.14	0.052481	3819.72
410	23.2335	37.2269	12.3135	0.624106	3807.53	0.055719	3942.9[illegible]
411	24.2146	38.5471	12.9092	.628181	4039.03	0.055529	4183.[illegible]
412	25.2978	39.8133	13.4878	0.635410	4266.32	0.056692	4416.91
413	26.1805	40.7016	13.8984	.643230	4429.68	0.057015	4586.9
414	26.3150	41.2439	14.1506	0.638032	4530.44	0.057767	4692.23
415	27.1093	42.1276	14.5641	0.645404	4696.28	0.057303	4861.69
416	27.2819	43.0256	14.9882	.634086	4868.13	0.058097	5043.26
417	28.2250	43.7583	15.3363	.645021	5009.55	0.057373	5186.44
418	28.9093	44.0537	15.7089	.649100	5162.04	0.056360	5343.15
419	29.2765	45.0610	15.9613	0.649700	5265.74	0.058618	5448.06
420	29.6022	45.9796	16.4059	.643821	5449.89	0.056106	5641.77
421	29.9311	46.4618	16.6412	.644210	5547.75	0.056388	5742.56
422	30.9634	47.1423	16.9742	.656808	5686.43	0.055298	5880.5
423	31.0473	47.3714	17.0666	0.655402	5733.58	0.056110	5928.41
424	31.5464	48.0664	17.4299	.656308	5877.96	0.055526	6077.32
425	32.2769	48.7071	17.7477	.662674	6011.98	0.05623	6213.81
426	32.3970	49.2891	18.0584	.657287	6135.92	0.055824	6345.70
427	32.9580	49.7418	18.2649	0.663185	6231.97	0.056056	6440.33
428	33.0731	50.1829	18.4864	.659051	6326.35	0.056383	6536.57
429	33.4675	50.632	18.7128	.660994	6423.10	0.056058	6633.97
401	12.0340	19.2373	5.0612	.605555	1053.90	0.111538	1298.21
402	15.0518	22.234	6.1454	.676974	1598.41	0.070367	1655.91
403	1[illegible].1361	25.173	7.2627	0.720455	1969.15	.075358	2041.13
404	20.4519	27.5463	8.1990	.740455	2291.37	0.101557	2376.56
405	22.7634	30.[illegible]45	9.2003	.758666	2646.19	0.090462	2746.21
406	24.4731	31.805[illegible]	9.9531	.769529	2919.53	.082709	3030.64
407	25.6112	33.1359	10.5199	.772913	3128.73	0.089365	3248.97
408	27.3456	34.8934	11.2614	.783699	3414.00	0.092614	3545.46
409	29.1828	36.6584	12.0609	.796074	3711.73	0.104667	3855.62
410	29.1061	37.2863	12.3417	.780513	3820.06	0.101483	3970.22
411	30.2714	38.4423	12.8629	.787449	4022.28	0.101045	4177.85
412	31.5687	39.6203	13.4006	.796781	4233.56	0.100003	4397.03
413	32.4602	40.5635	13.8356	0.800453	4406.11	0.104255	4576.43
414	33.5793	41.4747	14.2596	0.809632	4575.46	0.104035	4752.39
415	33.5982	41.8975	14.4573	0.801914	4654.74	.104096	4834.18
416	34.8239	42.6779	14.8253	.815971	4803.97	0.104059	4991.81
417	35.7082	44.0679	15.4854	.811433	5071.87	0.102748	5267.04
418	35.6918	44.7406	15.8069	.797750	5205.51	0.103180	5410.46
419	37.1028	45.5299	16.1896	.814912	5362.08	.103602	5566.23
420	37.7131	46.0769	16.4054	.818482	5472.55	0.104532	5680.82
421	38.0008	46.8186	16.8176	0.811659	5623.41	0.104650	5837.25
422	39.4644	48.0264	17.4126	.821722	5873.60	0.105395	6094.31
423	39.8351	48.7283	17.7008	0.817493	6020.50	0.100178	6245.26
424	40.4006	49.0224	18.2071	0.814765	6209.78	0.104738	6438.8
425	41.1465	49.7715	18.2824	0.826709	6242.50	0.103965	6474.57
401	15.5191	21.8623	6.0088	.709857	1553.80	0.068097	1617.83
402	20.1693	25.3101	7.3157	0.790887	1986.94	0.101389	2066.46
403	24.4430	28.3437	8.5203	.862378	2404.08	0.103292	2499.89
404	27.7007	30.9704	9.6020	0.894425	2791.27	0.107642	2902.93

UN CE	EXP NUSSELT	CRIM NUSSELT	COL NUSSELT	FTHETA	REYNOLDS	FRICTION	REYNOLDS(F)
05	30.2225	32.9458	10.4382	0.917342	3098.22	0.111655	3221.42
06	31.0502	34.2526	11.0021	0.926769	3308.98	0.111589	3443.60
07	32.7055	35.0428	11.6106	0.917595	3539.24	0.117211	3632.9[illegible]
08	33.9557	36.8382	12.1410	.901752	3742.40	0.118550	3894.57
09	35.7365	38.0210	12.7028	.934990	3983.38	0.119106	4144.44
10	37.1726	39.5020	13.3466	.941016	4212.29	0.117572	4381.32
11	38.1714	40.865	13.9756	0.934086	4462.05	.118743	4643.29
12	39.6993	41.6878	14.3091	0.952301	4615.26	0.120721	4798.45
13	40.6785	42.6827	14.8070	.953043	4804.00	0.121393	4993.56
14	41.6787	43.3711	15.2484	.956566	4975.14	0.119605	5169.63
15	42.1742	44.1357	15.5179	.955507	5085.28	0.119489	5283.35
16	43.1076	44.9918	15.9292	.958122	5254.27	0.118933	5458.90
17	44.9184	45.837	16.3083	.958143	5423.35	.120030	5633.32
18	44.8687	46.3742	16.5997	0.967535	5531.89	0.116516	5743.83
19	45.3292	46.7400	16.7789	.969817	5606.46	.116060	5821.44
20	45.2383	47.373	17.0290	.964939	5736.20	0.115208	5954.43
21	47.5233	48.533	17.6529	.979195	5978.13	0.117665	6204.27
22	47.2549	49.5764	18.1831	.953172	6198.49	.117636	6426.83
23	44.9457	46.3500	16.5882	.969702	5527.4	0.117315	5733.16
24	40.6539	41.028	14.0512	.976236	4492.07	0.115916	4659.29
25	33.7945	36.5199	11.9993	0.925373	3588.12	0.116046	3828.73
26	26.1626	29.0174	8.9997	.888346	2574.64	0.118566	2671.57
401	20.6170	22.8489	6.3755	.902317	1672.89	.200989	1738.01
402	21.9623	25.0878	7.2292	.875418	1957.46	0.179128	2038.20
403	25.3063	27.8455	8.3189	.908812	2332.97	0.199569	2430.8
404	27.6303	30.2556	9.3040	.913228	2683.31	0.196740	2798.83
405	29.4767	31.6234	9.8762	0.932116	2891.14	.191873	3015.13
406	32.1398	34.0047	10.8943	.945159	3268.37	0.188939	3410.40
407	33.9032	35.2902	11.4552	0.963247	3480.02	0.179402	3629.54
408	36.6451	37.4249	12.4037	.979164	3843.85	0.186052	4010.48
409	37.2313	38.5083	12.8931	.966837	4034.34	.189989	[illegible]
410	38.2012	39.4701	13.3519	.970132	4206.70	0.186357	4389.84
411	39.1360	40.5567	13.8307	0.964969	4405.14	0.187214	4597.93
412	40.1589	41.3137	14.1046	0.972048	4545.66	0.184336	4744.21
413	42.5352	41.4555	14.4849	1.013817	4666.25	0.1885[illegible]	4865.24
414	43.8627	43.1914	15.0683	1.015542	4902.35	0.184658	5109.99
415	43.9031	43.8863	15.3991	1.002433	5037.20	0.183219	5248.8[illegible]
416	44.2072	44.669[illegible]	15.7743	.991675	5191.02	.188035	5407.35
417	47.0036	47.1377	16.9743	0.997154	5689.29	0.185295	5928.
418	46.8113	47.8519	17.3262	.978255	5837.07	0.181795	6081.7[illegible]
419	46.3604	48.0156	17.7043	0.953611	5996.91	.183349	6247.40
42	44.1878	45.4643	16.1581	.971923	5349.31	0.183486	5557.6[illegible]
421	43.8060	45.2042	16.0322	.969071	5297.28	.185548	5513.8
422	43.1869	44.3631	15.6073	0.973467	5130.57	0.181272	5339.64
423	42.6785	42.2635	14.6295	1.009820	4724.43	0.186872	4912.47
424	41.2718	39.4631	13.3286	1.045833	4205.24	0.178521	4369.98
425	34.7132	34.1757	10.9684	1.015728	3296.03	.186586	3423.51
426	30.4062	29.8789	9.148	1.017647	2627.04	0.192319	2724.06

APPENDIX G

Convection Heat Transfer Regression Analysis

A regression analysis is applied to the results of the data reducing computer program, the purpose of which is to fit a curve of the generalized type, $Y = A + BX^m$ through the reduced data. The independent variable X is the experimental value of the Reynolds Number through the test section, defined throughout this text as BNRE. The indepenaent variable Y is the ratio of the Nusselt Number as measured experimentally to the Nusselt Number computed from the modified Grimison equation, defined by FTHETA. The results of this regression analysis will be the constants A and B, and the exponent M resulting in an equation relating FTHETA to Reynolds Number BNRE, within the range of the experimental data. From this equation, particularized for the angle of inclination and the tube geometry, the angle factor FTHETA may be computed, or taken from design-oriented curves to apply as an additional factor to the modified Grimison Equation.

The analysis was carried out using a prepared program available at the Applied Mathematics Laboratory of the David Taylor Model Basin. The program is written in Bell FORTRAN II for the IBM 7090 computer. Running time is 2.5 minutes. The program is documented in DTMB Report 2037.

A brief description of the program is included in this Appendix.

A maximum of 35 data points may be entered as input for any one case. The program will fit a function of the form $Y = A+B\ X^M$ to the data points entered by the method of least squares. The line of regression will be calculated and plotted three times using three sets of data points, the first being the entire original set of data points, the second being the set of points within two standard errors, and the third using those points which fall within one standard error. The standard error is defined as:

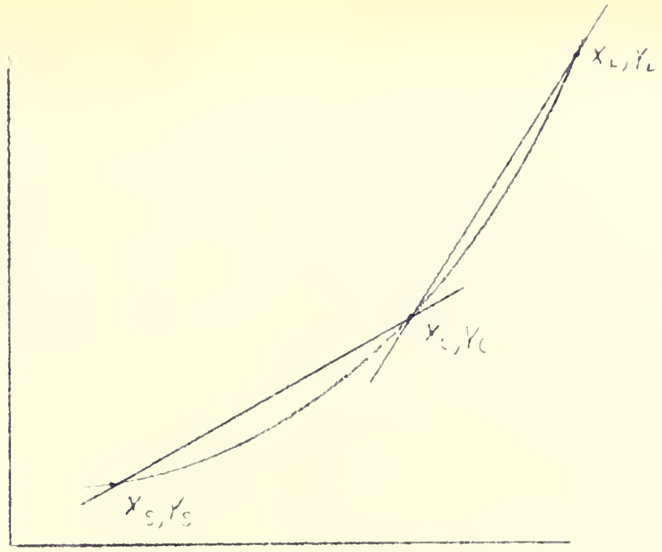
$$SE = \sqrt{\sum_{i=1}^{N} \frac{(Y_i - Y_{ave})^2}{N}}$$

where: Y average is the average ordinate of all the points.

Yi is the general ordinate when i is indexed from 1 to N.

N is the number of points.

The method used by the program is the method of least squares. An approximation to the exponent M is made by using the first three and the last three points, averaging the ordinates and abcissas of these points to derive an average point, X average. Four points, (two greater than and two less than) closest to X average are taken. From these four points, a new average point is derived. The slopes of the upper and lower portion of the first approximate line of regression are then determined. Dividing the lower slope by the upper slope, an expression exists from which the exponent M may be approximated.



$$X_S = \frac{X_1+X_2+X_3}{3} \qquad Y_S = \frac{Y_1+Y_2+Y_3}{3}$$

$$X_L = \frac{X_n+X_{n-1}+X_{n-2}}{3} \qquad Y_L = \frac{Y_n+Y_{n-1}+Y_{n-2}}{3}$$

$$X \text{ avg.} = \frac{X_S+X_L}{2}$$

The four values of X closest to X avg. are located.

$$X_C = \frac{X_{i-2} + X_{i-1} + X_i + X_{i+1}}{4}$$

$$Y_C = \frac{Y_{i-2} + Y_{i-1} + Y_i + Y_{i+1}}{4}$$

in which X_i = X avg.

Then the exponent M may be determined in the following manner:

$$Y = A + BX^M$$

$$\frac{dy}{dx} = BMX^{M-1}$$

Two slopes may be written from Fig. A

(1) $$\frac{Y_C - Y_S}{X_C - X_S} = BM \left(\frac{X_C + X_S}{2}\right)^{M-1}$$

where $\frac{Y_C - Y_S}{X_C - X_S}$ is the slope at $\frac{X_C + Y_S}{2}$

(2) $$\frac{Y_L - Y_C}{X_L - X_C} = BM \left(\frac{X_L + X_C}{2}\right)^{M-1}$$

where $\frac{Y_L - Y_C}{X_L - X_C}$ is the slope at $\frac{X_C + X_C}{2}$

Dividing equation (2) by equation (1).

$$\frac{(Y_L - Y_C)\ (X_C - X_S)}{(X_L - X_C)\ (Y_C - Y_S)} = \left(\frac{X_L + X_C}{X_C + X_S}\right)^{M-1}$$

Now let $\frac{(Y_L - Y_C)\ (X_C - X_S)}{(X_L - Y_C)\ (Y_C - Y_S)} = D$

Let $\frac{X_L + X_C}{X_C + X_S} = E$

$$D = E^{(M-1)}$$

$$\text{LnD} = (M-1) \ln E$$

Then $M = \frac{\ln D}{\ln E} + 1$

which provides an approximation to M.

The initial approximation of the exponent is testing for accuracy by considering seven values of the exponent, M being the center value and the others 1/4 M from this central value in

increasing and decreasing increments.

For each value of the exponent, the values of A, and B are computed, and the sums of the squares of the derivations are minimized. The exponent, M, is then chosen from the set of A, B, and M that has yielded the minimum sum of the derivations squared.

The normal equations for the function $Y = A + BX^M$ with A, B, and M as the regression parameters.

$$nA + B \sum X_i^M - \sum Y_i = 0$$

$$A \quad X_i^M + B \sum X_i^{2M} - \sum Y_i X_i^M = 0$$

$$A \sum_i \ln X_i \; X^M + B \sum X_i^{2M} \ln X_i - \sum Y_i X_i^M \ln X_i = 0$$

These equations are solved for A and B by Cramer's Rule. The final test for the proper exponent is made by examining the coefficients of the three normal equations, i.e., three equations in two unknowns. Since A and B are unique, two of the three equations must be linearly dependent and the determinant of the coefficients will be identically equal to zero.

$$\begin{vmatrix} n & X_i^M & Y_i \\ X_i^M & X_i^{2M} & Y_i X_i^M \\ M \; X_{iX}^M & X_i^{2M} \ln X_i & Y_i \; X_i^M \ln X_i \end{vmatrix} = 0$$

This is true because the coefficients of one equation must be equal or proportional to the coefficients of another. It can now be seen that successive iterations based on estimates of M until the determinants of the coefficients are equal to zero to finalize the value of the coefficient M.

The exact values of A and B can then be calculated using Cramer's rule.

The output of the program appears in two forms. One form is the regular output of the 7090 program which states the A and B coefficients and the exponent M for each of the three lines of regression. The output of a typical analysis is shown on page 134 for examination. Note that with the lines of regression for points within two and one standard error, those points which were not used in the determination of the line are listed with the results. This list of points is cumulative through the two cases. The identifying information which accompanies each data point is placed in the computer along with the data at the choice of the user of the program. The second form of output is through the SC 4020 Charactron. The coding for this output is contained in a subroutine package named AMPFOS and the form of the output is microfilm copies of the actual lines of regression. Although these plots have little value from the practical standpoint, due to the selection by the program's coding of rather cumbersome scales, the plots do indicate the validity of the curve fit and permit selection of one of the three lines as being most representative of the points. This output form is shown on page 135.

REGRESSION COEFFICIENTS FOR ALL INPUT POINTS

A = 0.72315S2E 00 B = 0.3546874E-04 M = [illegible].99890[illegible]E 0

GRAPH LEGEND

RNCD 3601 A	RNCD 3602 B	RNCD 3603 C	RNCD 3604 D	RNCD 3605 E	RNCD 3606 F
RNCD 3607 G	RNCD 3608 H	RNCD 3609 I	RNCD 3610 J	RNCD 3611 K	RNCD 3612 L
RNCD 3613 M	RNCD 3614 N	RNCD 3615 O	RNCD 3616 P	RNCD 3617 Q	RNCD 3618 R
RNCD 3619 S	RNCD 3620 T	RNCD 3621 U			

REGRESSION COEFFICIENTS FOR POINTS WITHIN TWO STANDARD ERRORS

A = 0.7262198E 00 B = 0.1741723E-03 M = [illegible].8012598E 0

POINTS THAT WERE NOT USED IN CALCULATION OF SECOND LINE OF REGRESSION

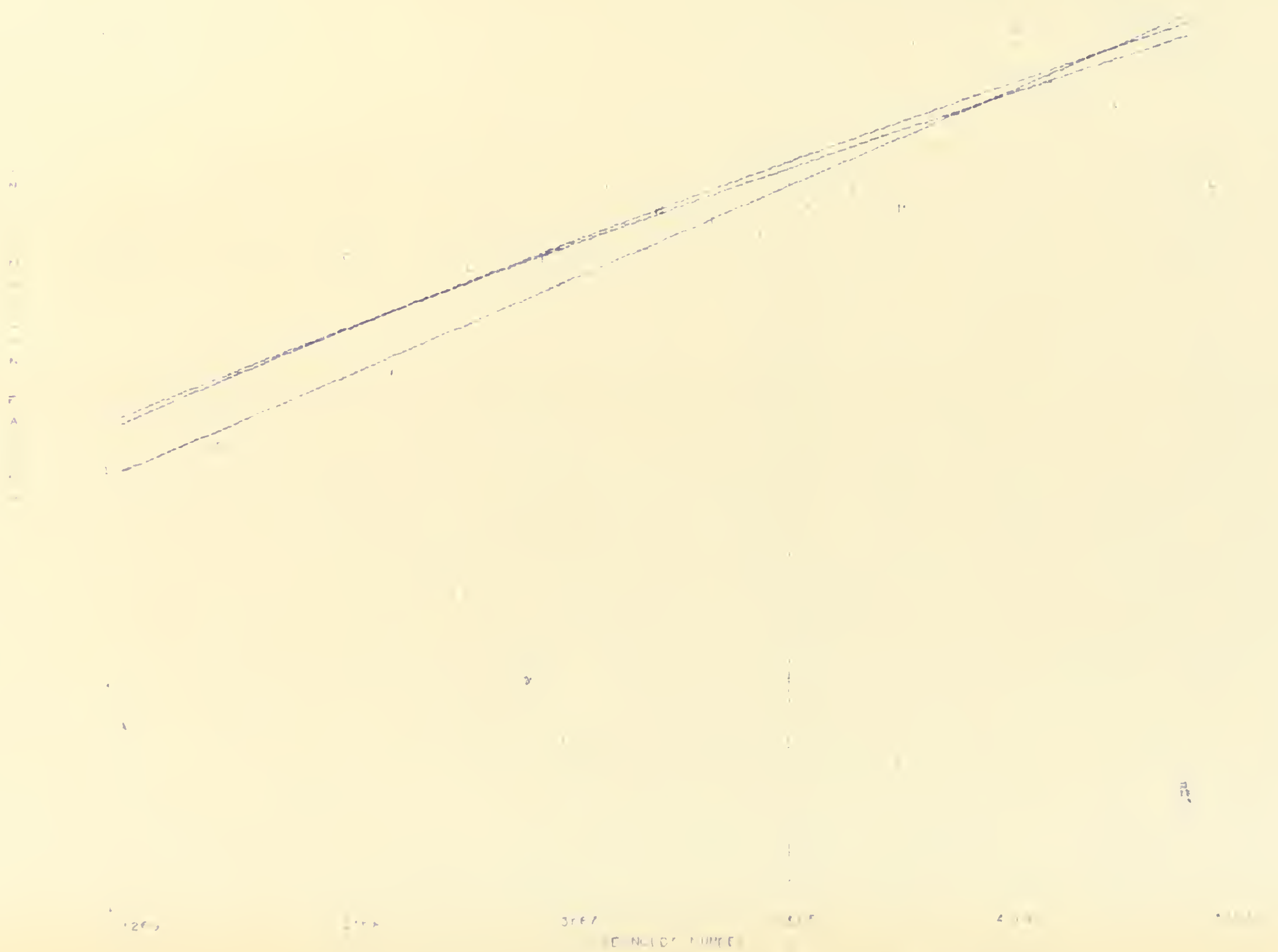
RNCD 3601 A RNCD 3621 U

REGRESSION COEFFICIENTS FOR POINTS WITHIN ONE STANDARD ERRORS

A = 0.7327494E 00 B = 0.1413496E-03 M = .6184397E [illegible]

POINTS THAT WERE NOT USED IN CALCULATION OF THIRD LINE OF REGRESSION

RNCD 3615 O

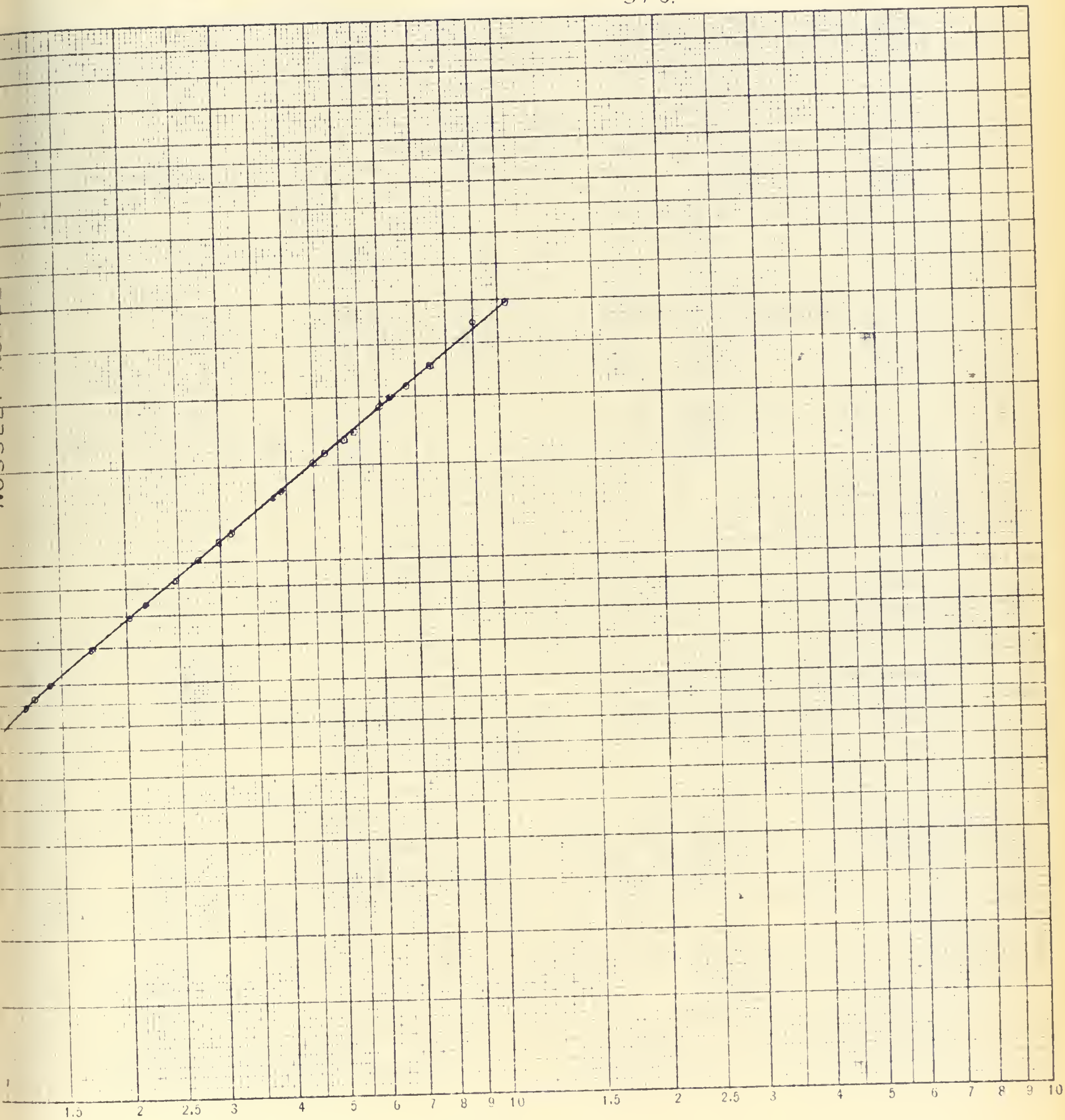


INCLINATION FACTOR VS REYNOLDS NUMBER # 11

Results of Data Reduction

Figures 27 thru 60 which follow are plots of Nusselt Number versus Reynolds Number for individual geometries and angles. Curves for θ = 90, 75, 60, 45 and thirty degrees are plotted using experimentally derived data, other curves for each geometry are also plotted using the Colburn and Grimison equations.

NUSSELT NUMBER
BY
COLBURN EQUATION
$S_L = S_T = 1.5\,D_T$
STG.



REYNOLDS NUMBER $\times 10^{-3}$

FIG. 27

NUSSELT NUMBER
BY
GRIMISON EQUATION
$S_T = S_L = 1.5 D_T$ STG.

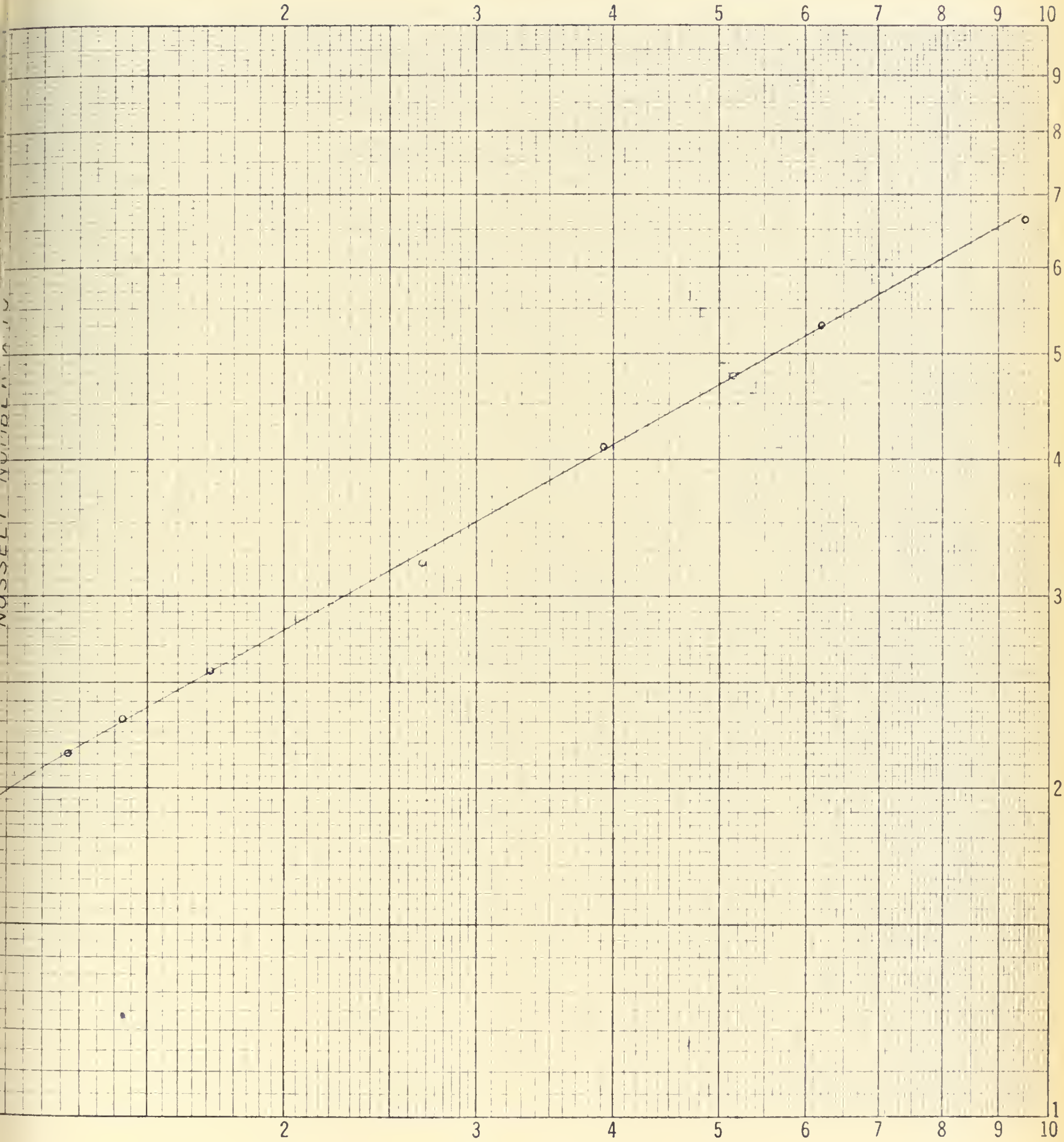


FIG. 28

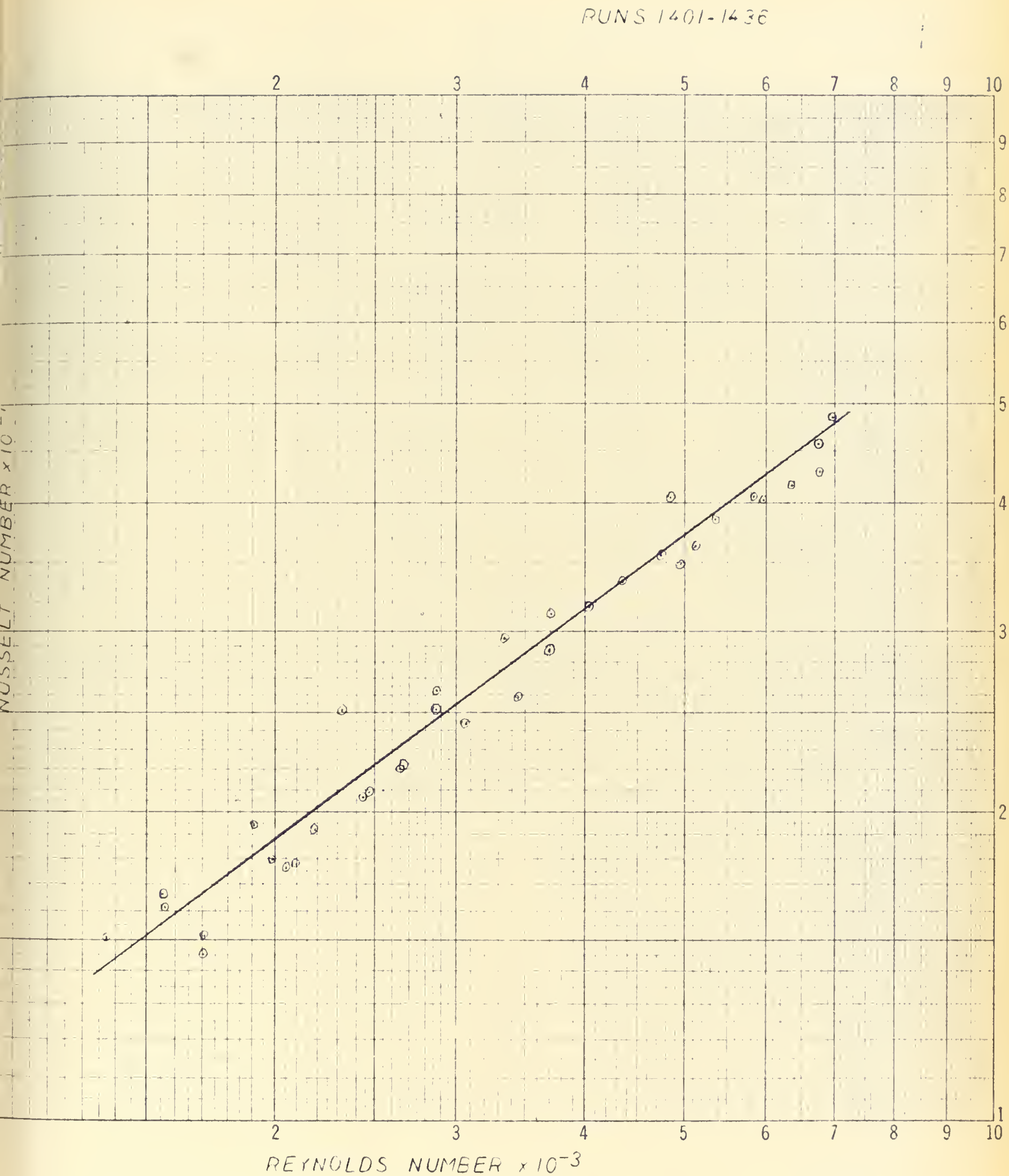

RUNS 1401-1436
2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
NUSSELT NUMBER x 10⁻¹
REYNOLDS NUMBER x 10⁻³

FIG. 29

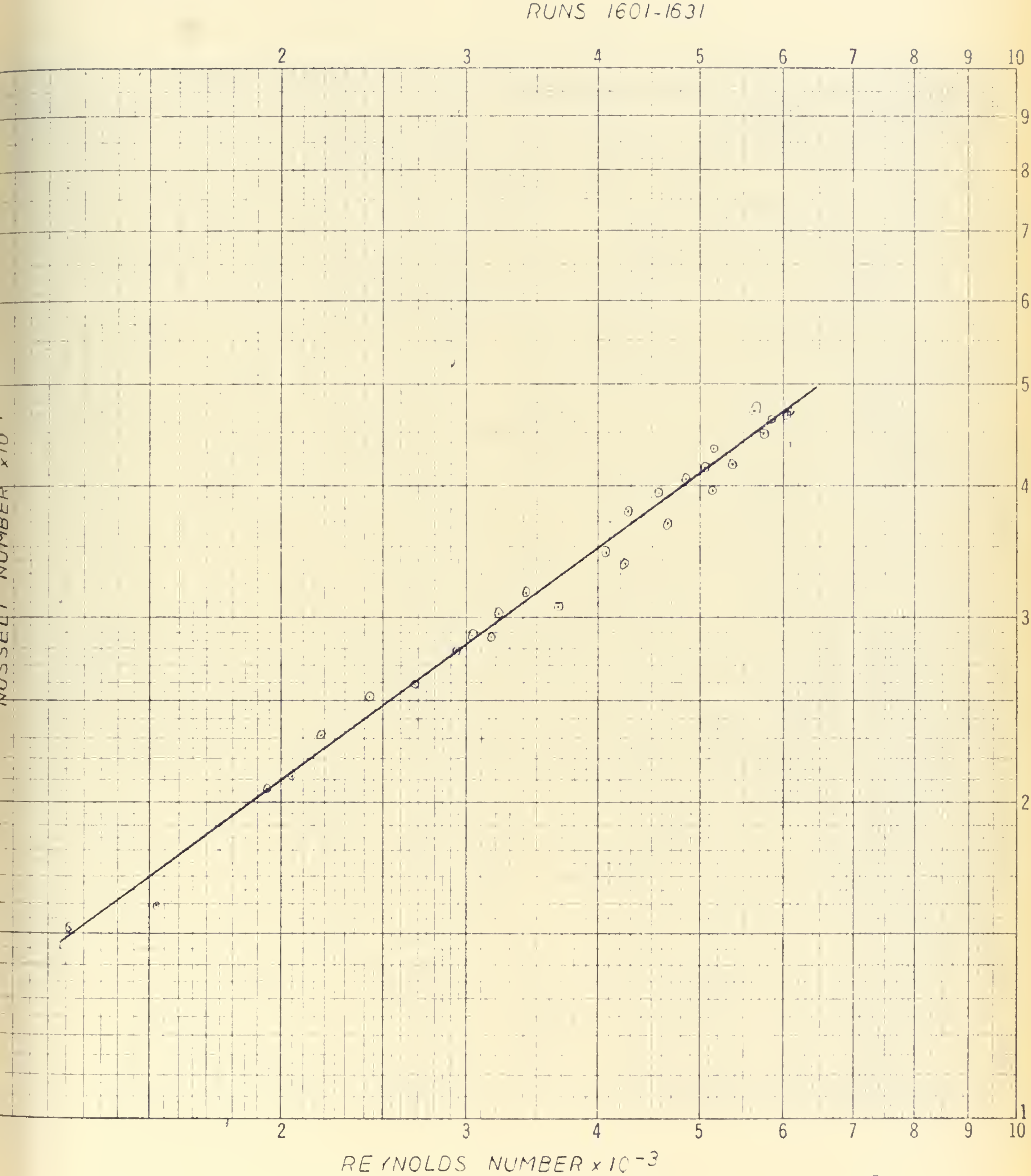

RUNS 1601-1631
2
3
4
5
6
7
8
9
10
NUSSELT NUMBER x10⁻¹
REYNOLDS NUMBER x 10⁻³

FIG 30

RUNS 1701-1718

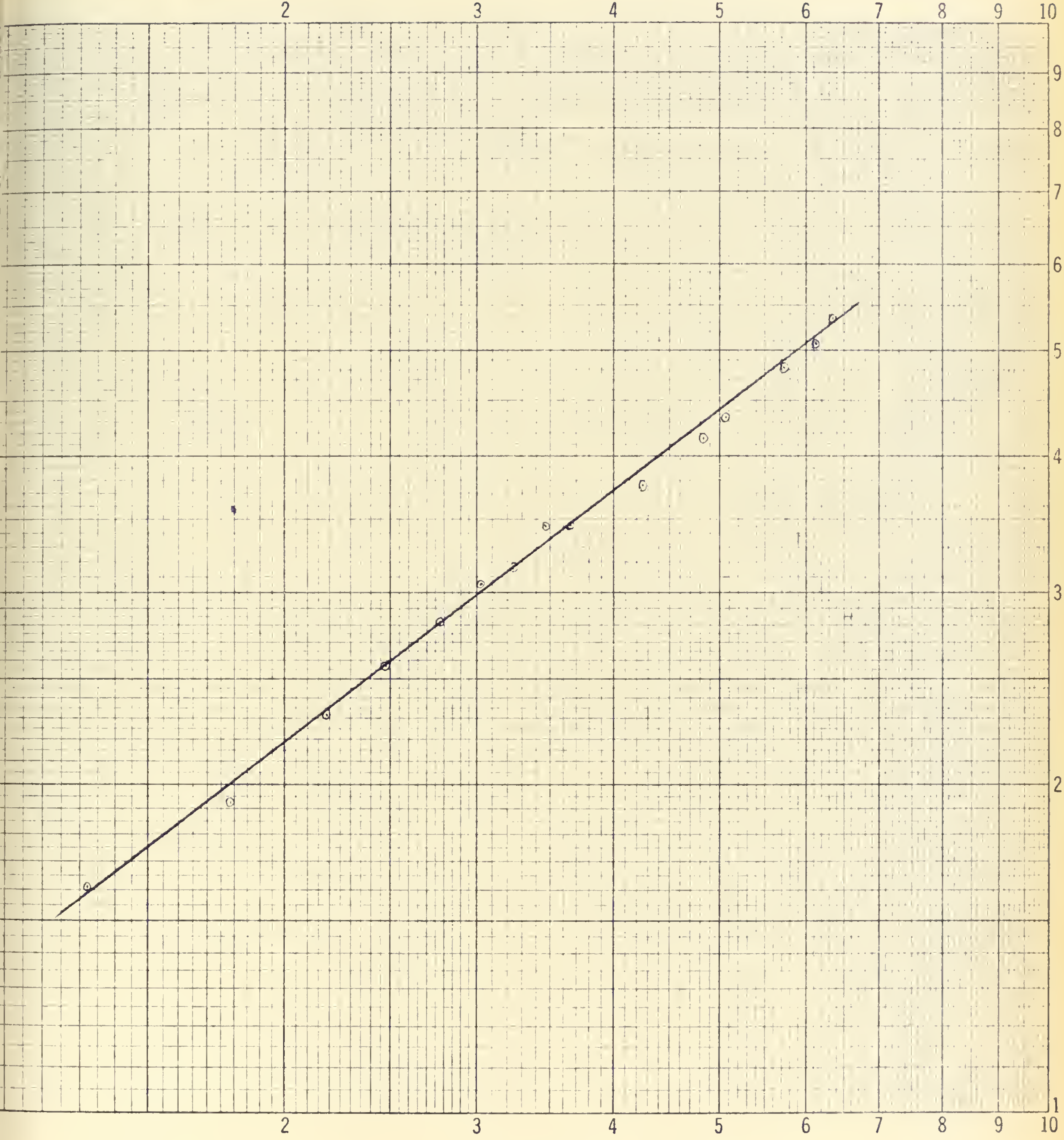


FIG 31

RUNS 1901 - 1930

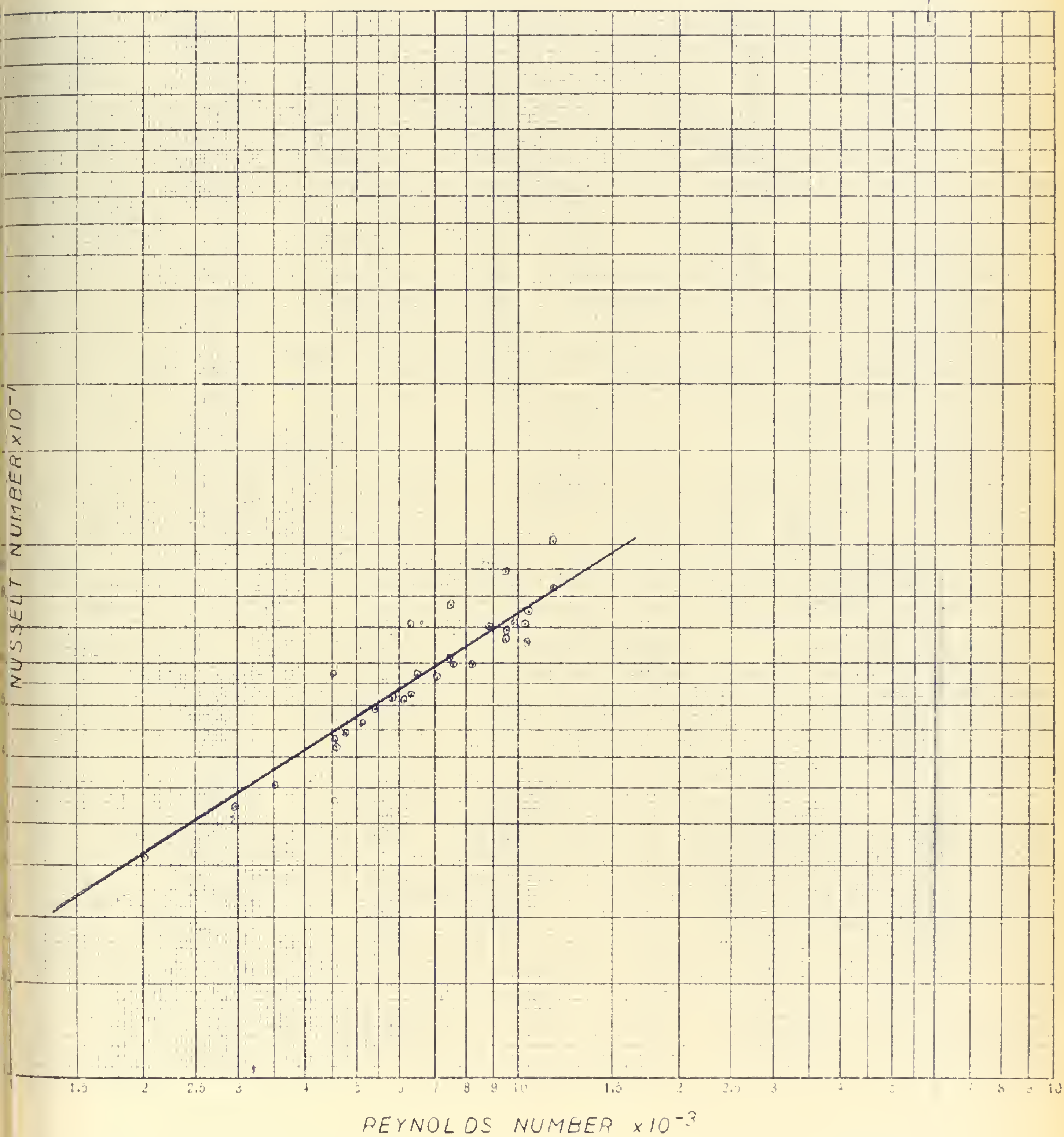


FIG. 32

NUSSELT NUMBER
BY
COLBURN EQUATION
$S_T = S_L = 1.5 D_T$ IN LINE

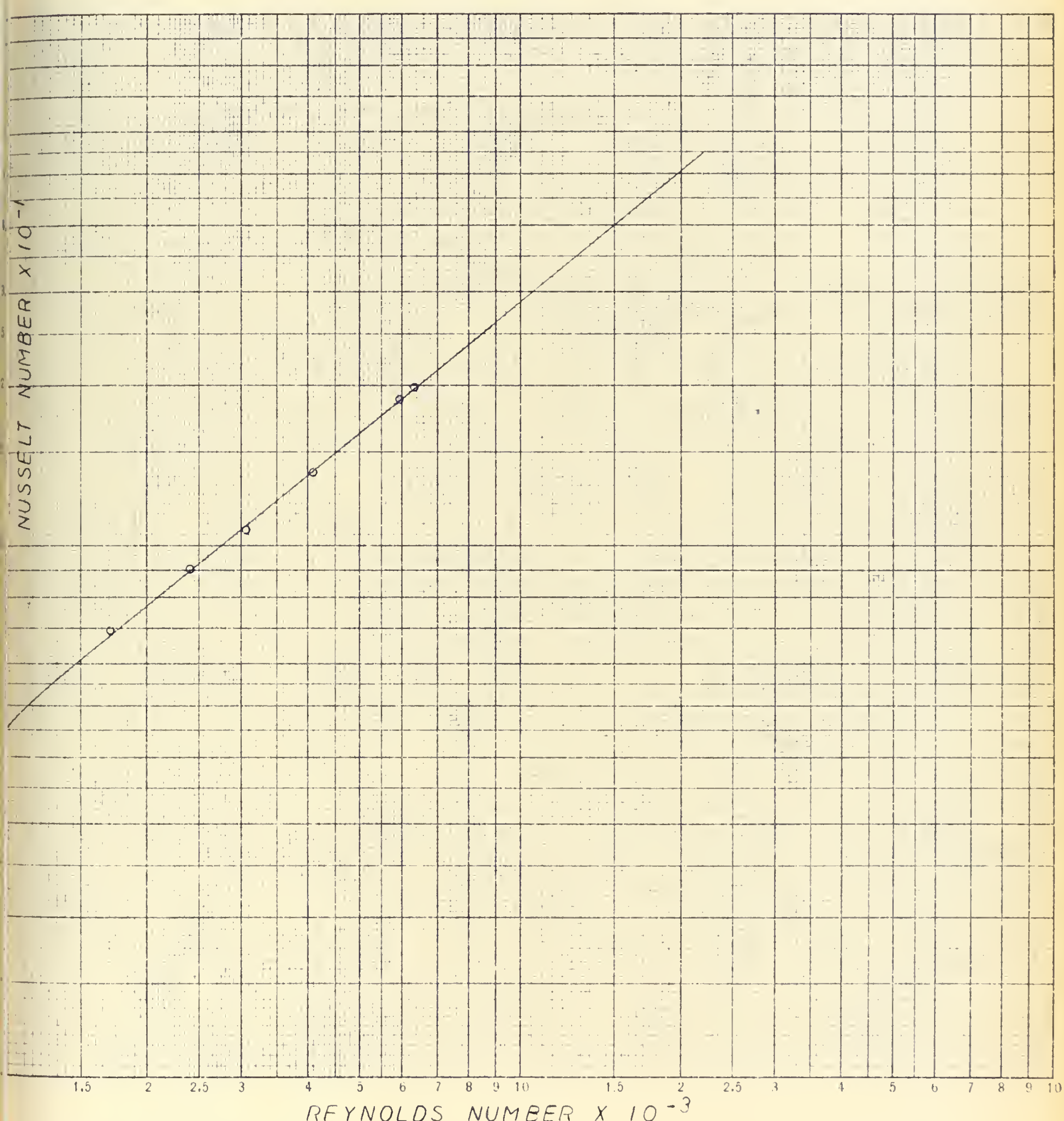


FIG. 33

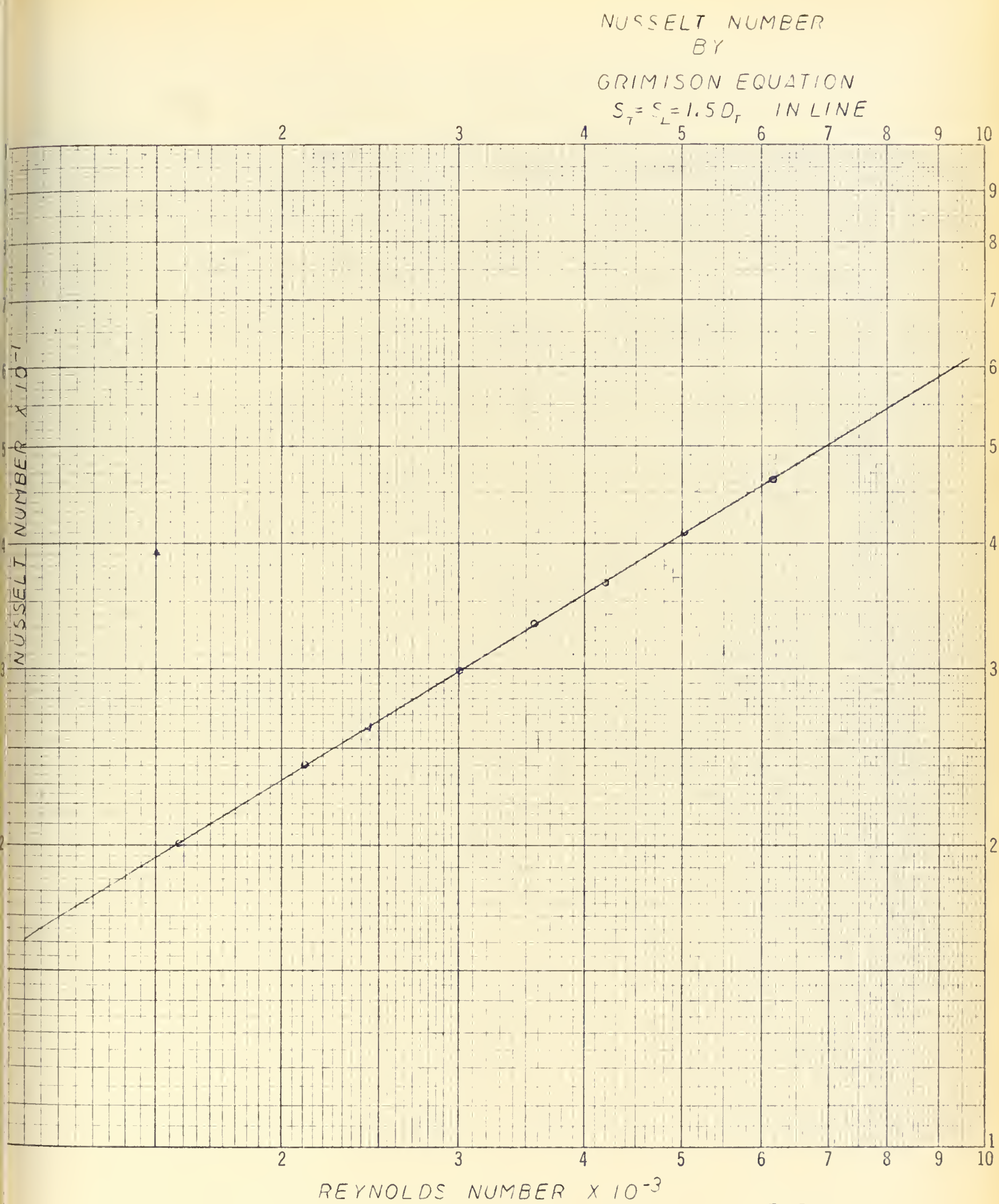

NUSSELT NUMBER
BY
GRIMISON EQUATION
$S_T = S_L = 1.5 D_T$ IN LINE
NUSSELT NUMBER X 10^{-1}
REYNOLDS NUMBER X 10^{-3}

FIG. 34

RUNS 2301 - 2316

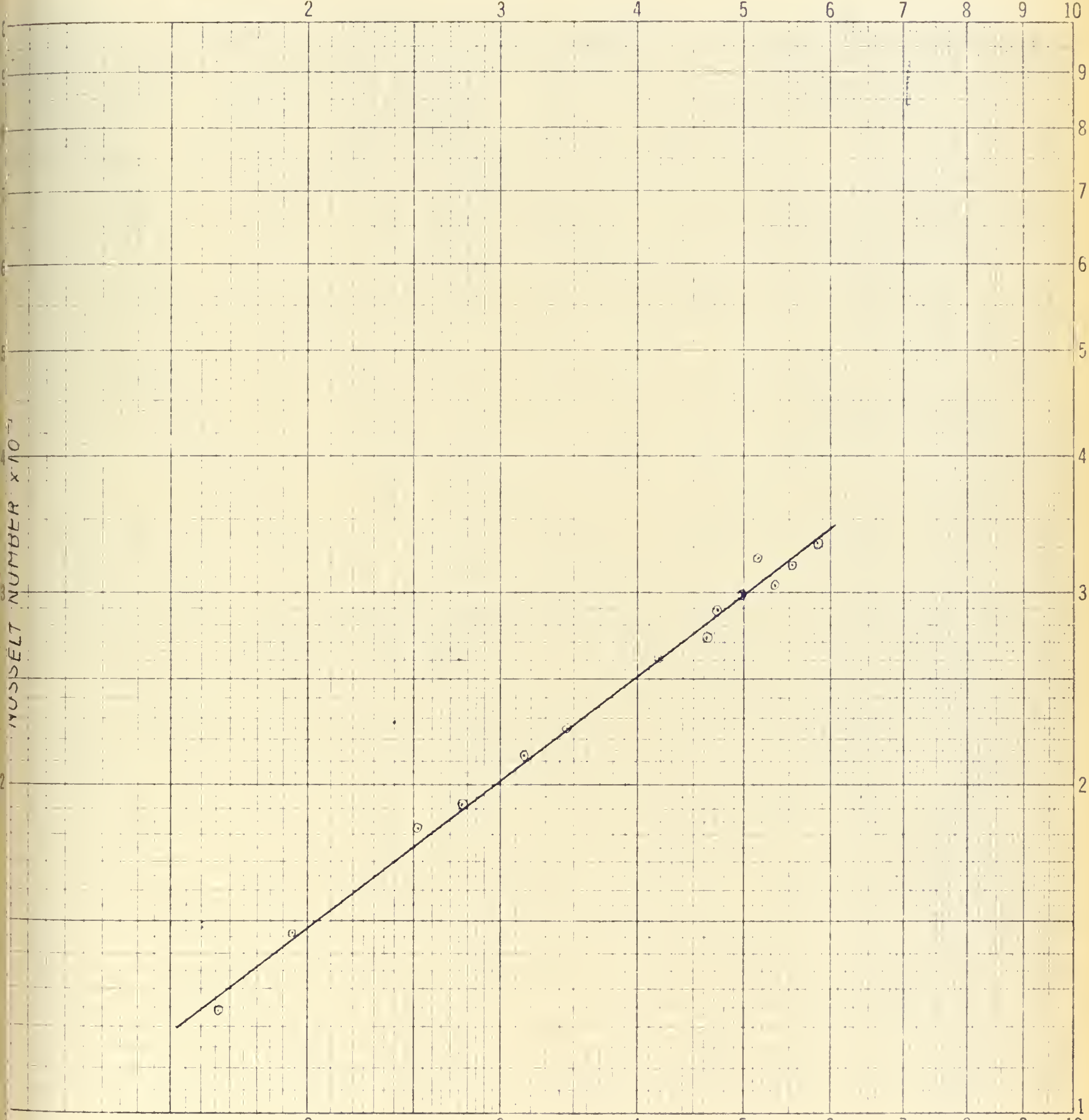


FIG. 35

RUNS 2401-2428

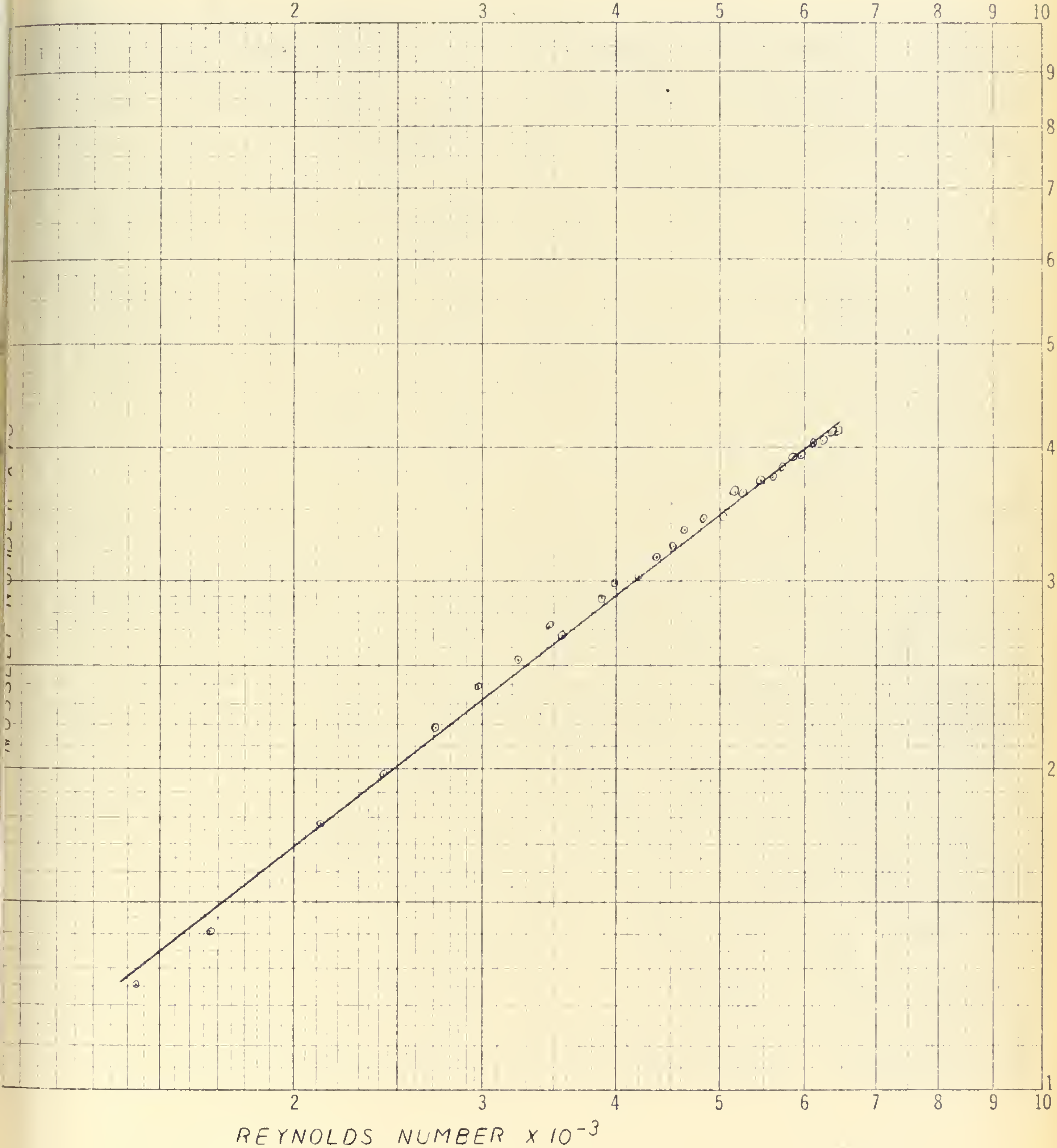


FIG. 36

RUNS 2601-2626

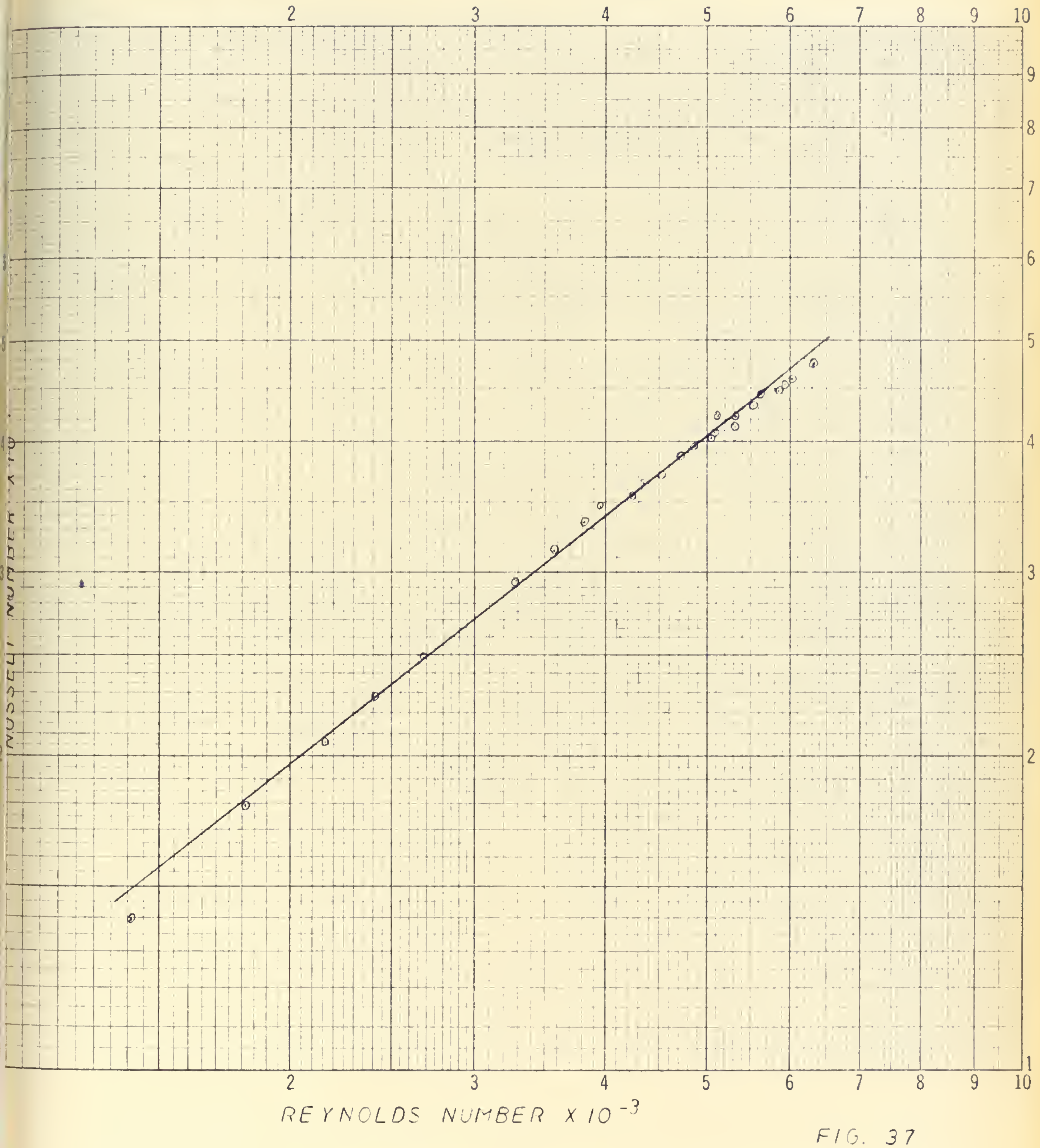


FIG. 37

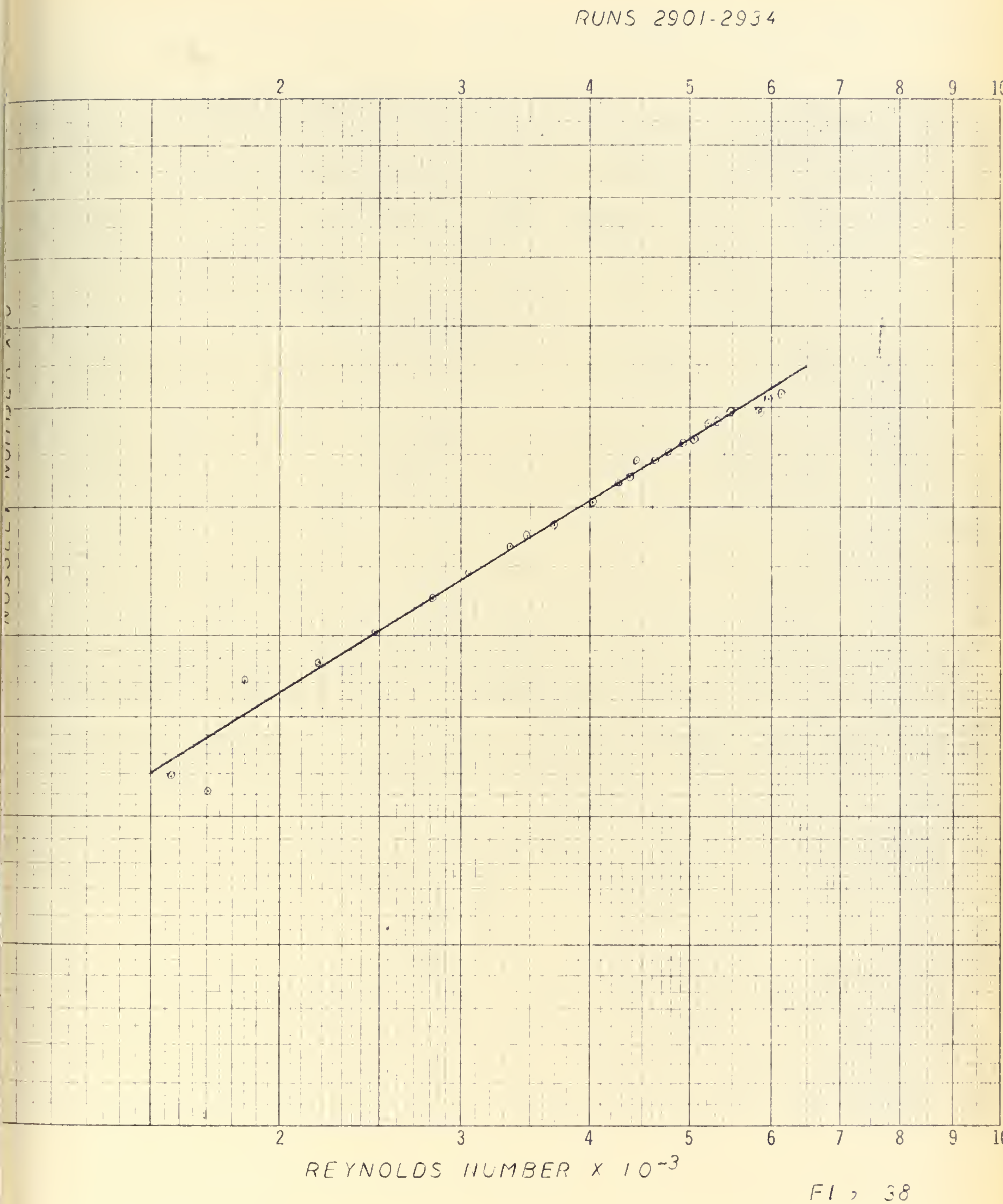


FIG. 38

NUSSELT NUMBER
BY
COLBURN EQUATION
$S_L = 1.5 D_T \quad S_T = 2.0 D_T$ STG.

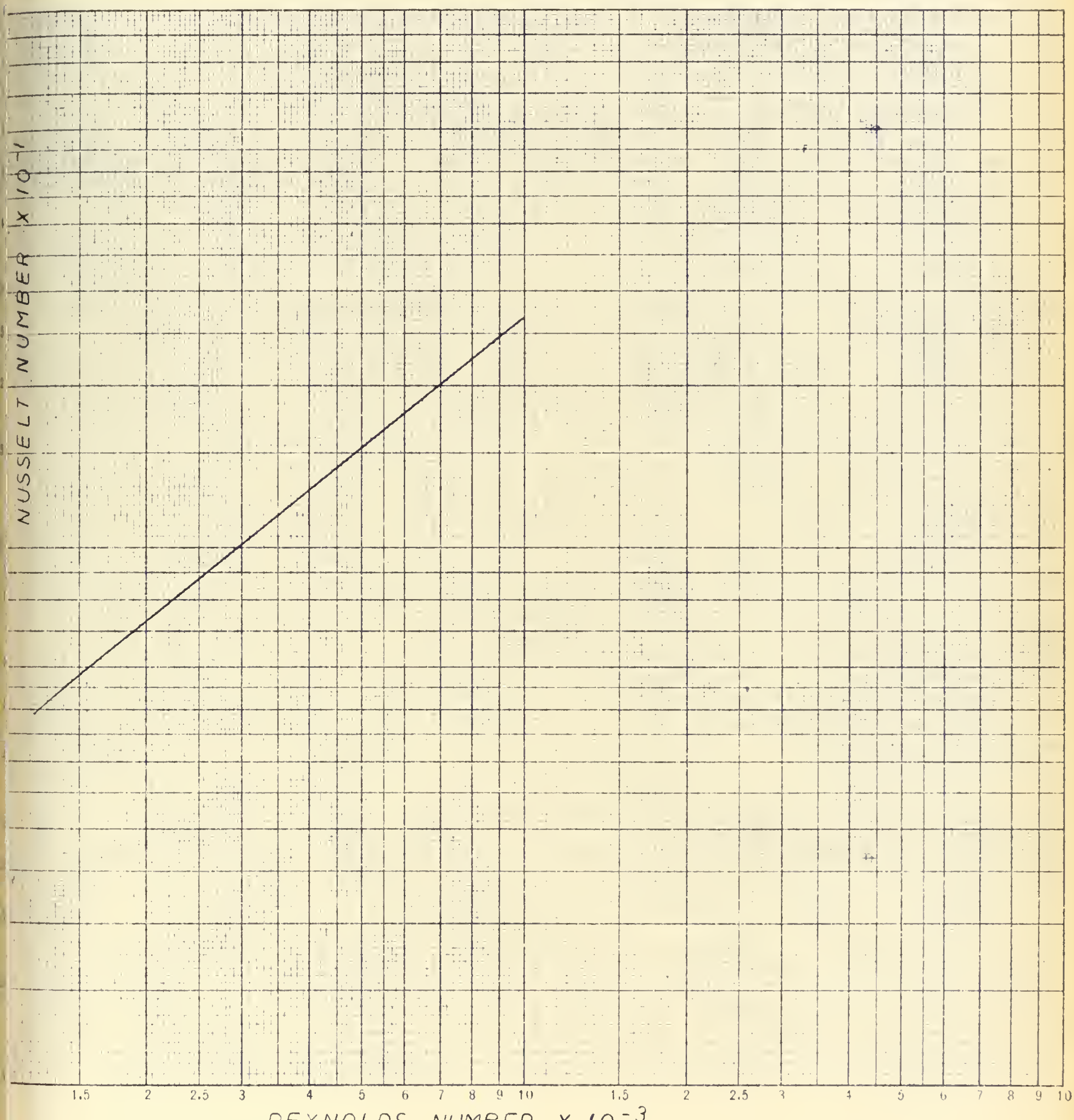


FIG. 39

NUSSELT NUMBER
BY
GRIMISON EQUATION
$S_T = 1.5 D_T \quad S_L = 2.0 D_T$ STG.

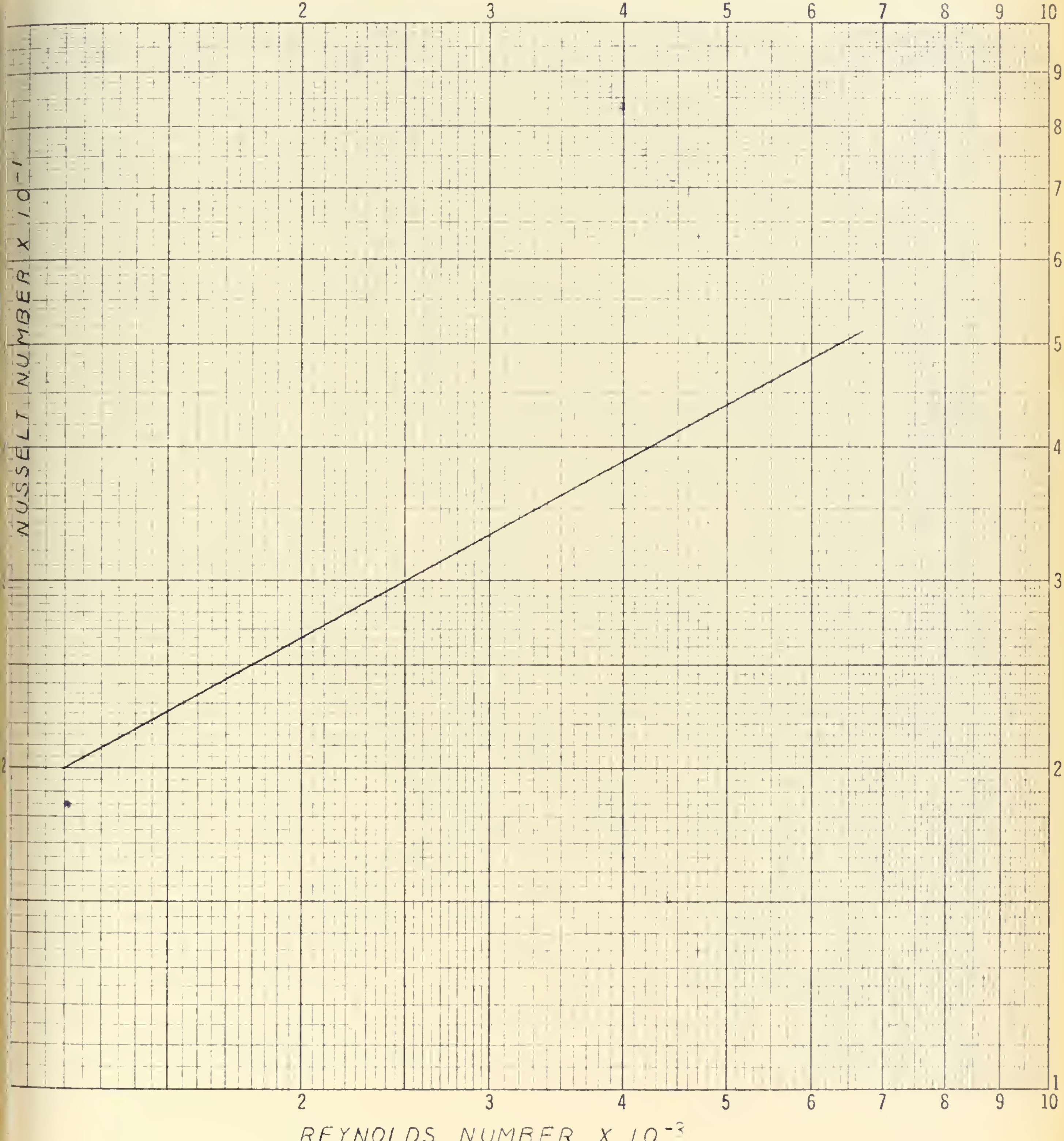


FIG. 40

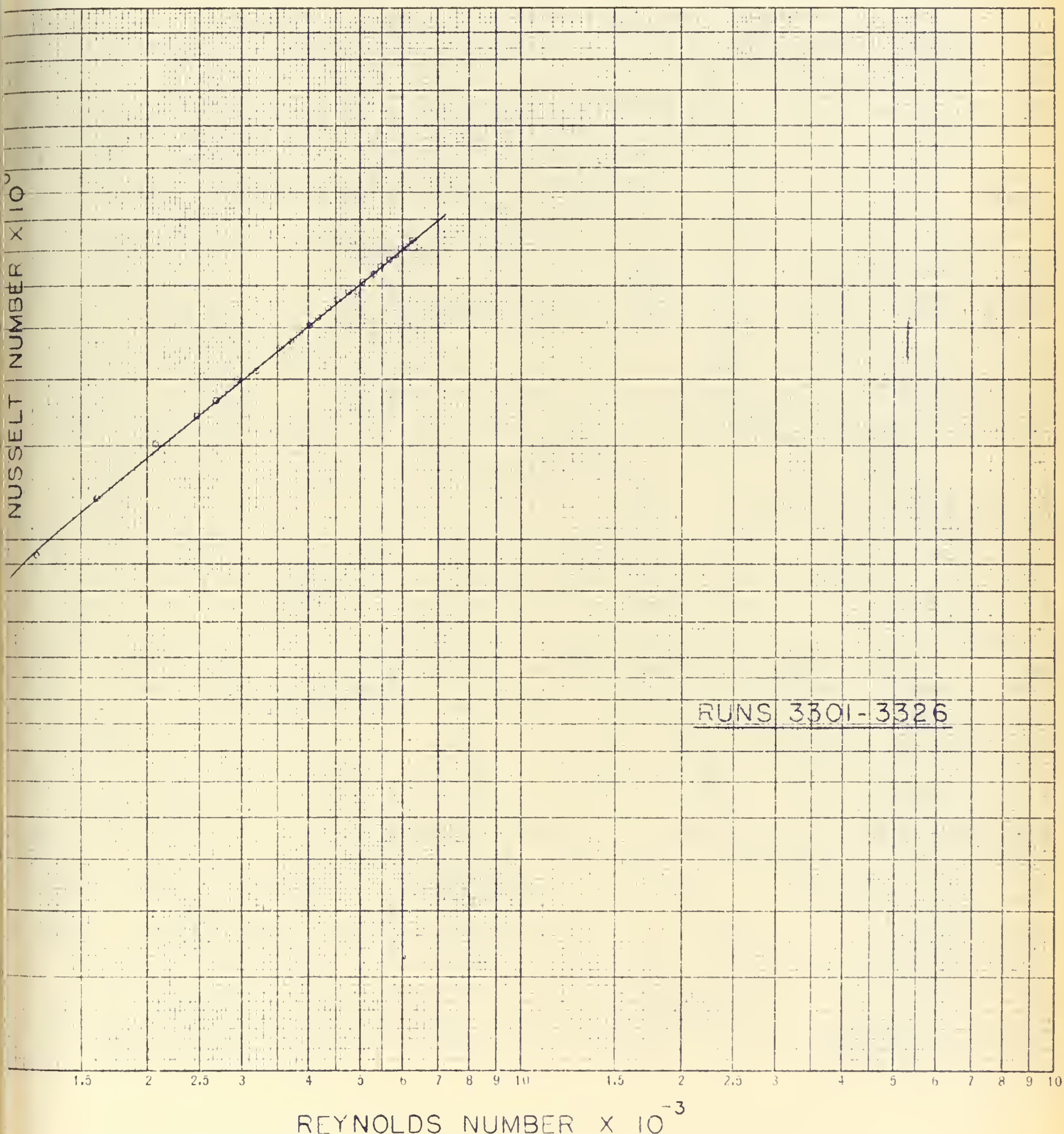

NUSSELT NUMBER X 10
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
9
10
REYNOLDS NUMBER X 10^{-3}
RUNS 3301-3326

FIG. 41

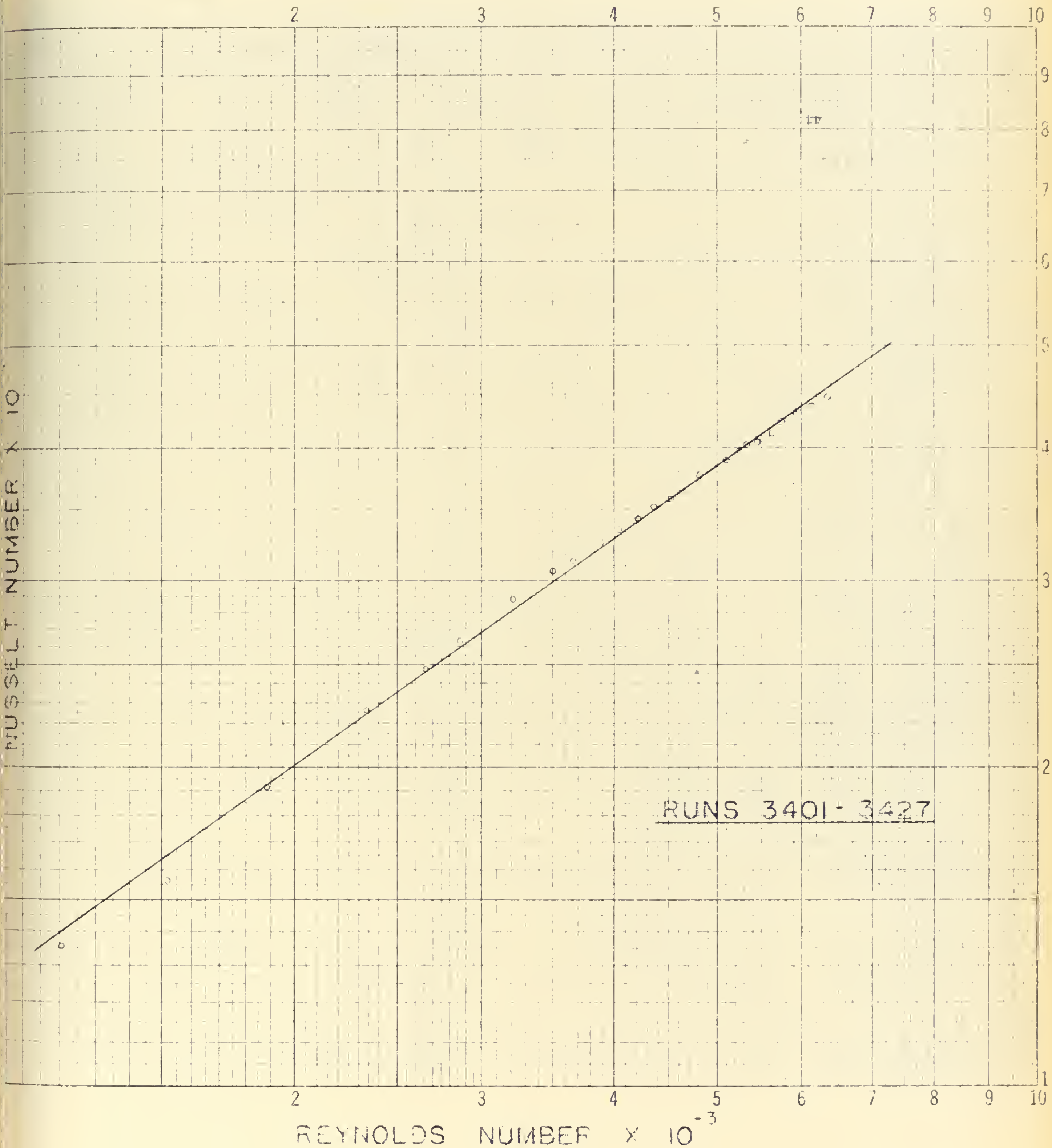


FIG. 42

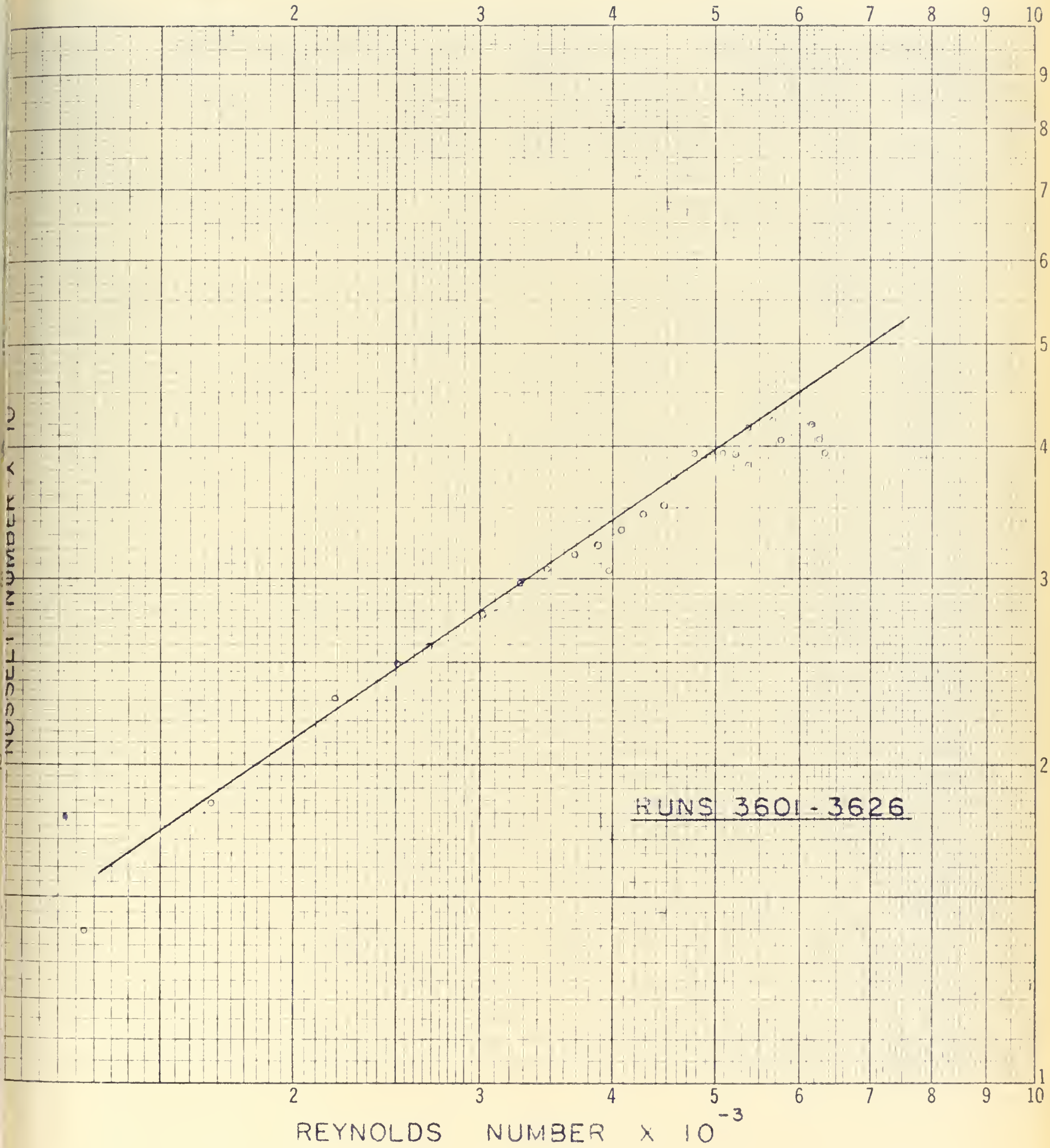
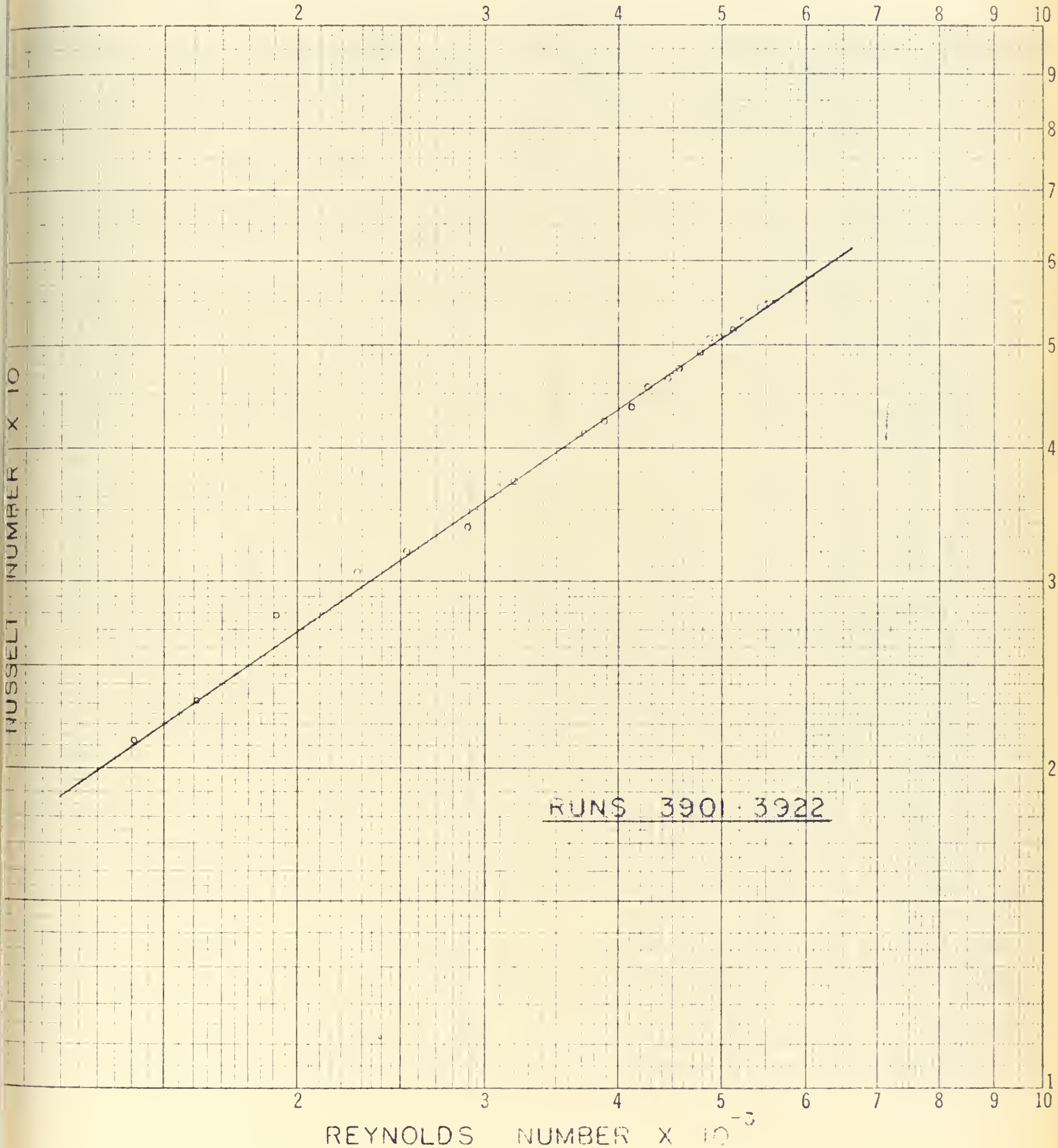


FIG. 43



2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
RUNS 3901-3922
NUSSELT NUMBER X 10
REYNOLDS NUMBER X 10⁻³

FIG. 44

NUSSELT NUMBER
BY
COLBURN EQUATION
$S_T = 1.5 D_T$ $S_L = 2.0 D_T$
IN LINE

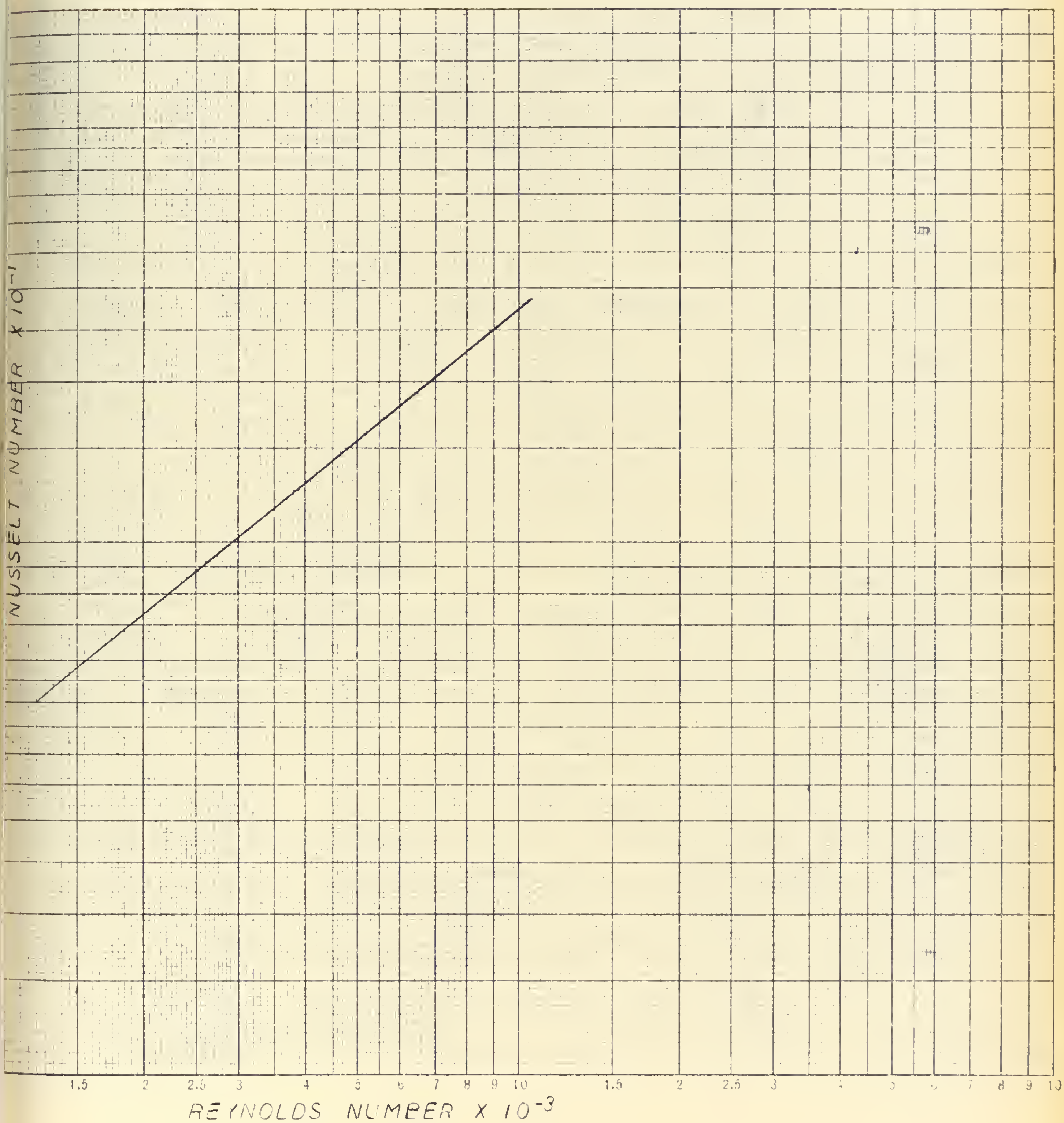


FIG 45

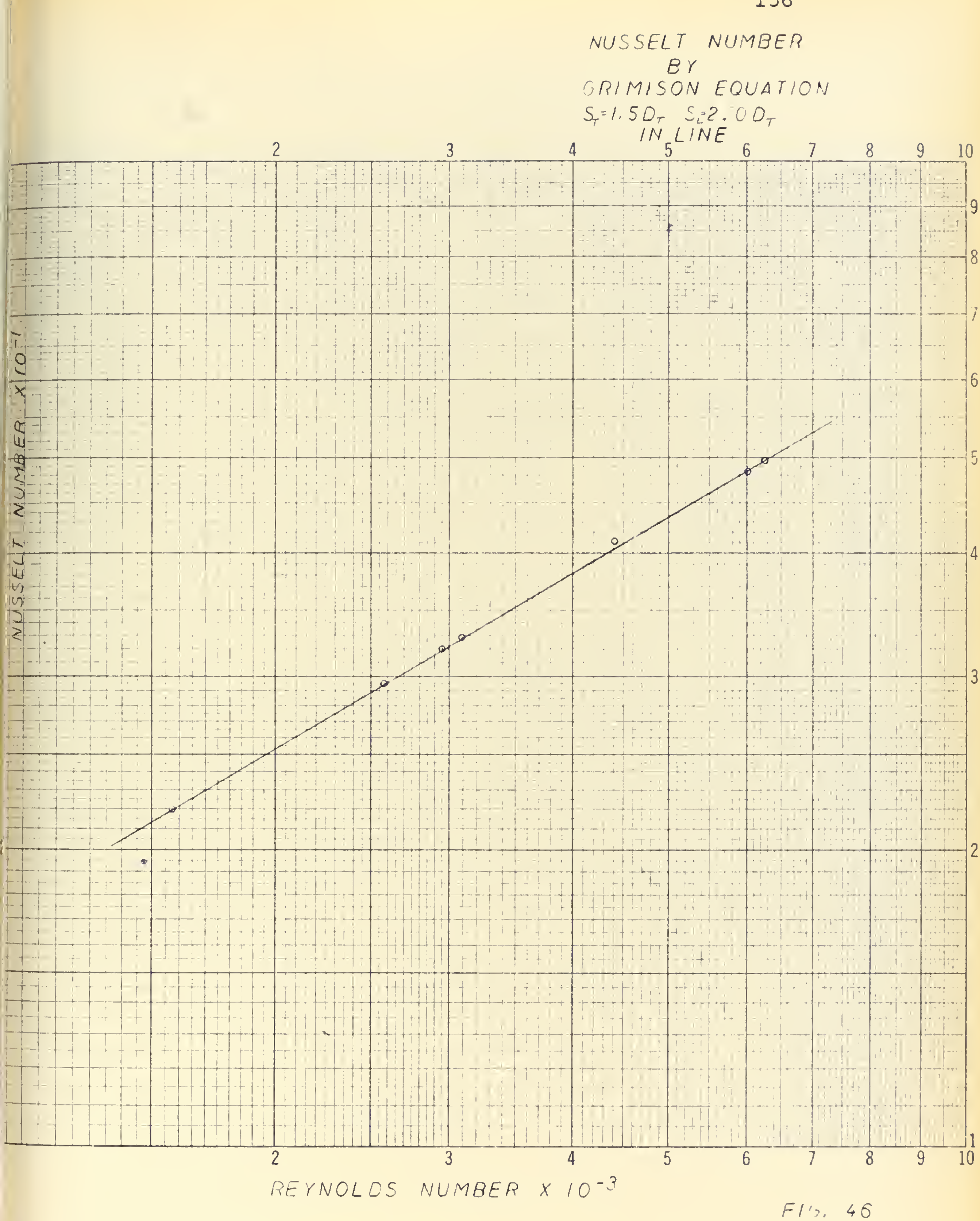
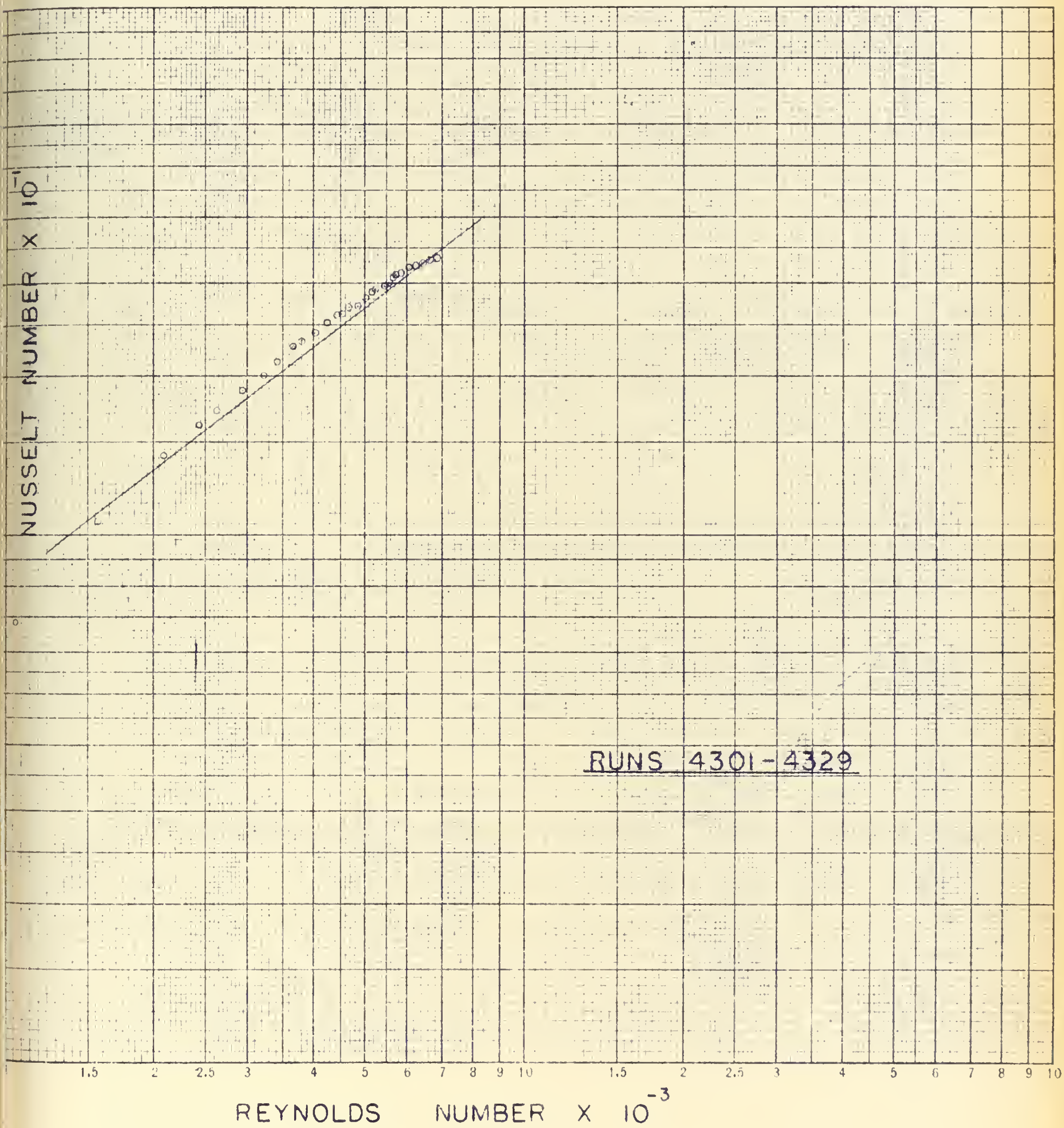

NUSSELT NUMBER
BY
GRIMISON EQUATION
$S_T = 1.5 D_T$ $S_L = 2.00 D_T$
IN LINE
NUSSELT NUMBER X 10⁻¹
REYNOLDS NUMBER X 10⁻³

FIG. 46



NUSSELT NUMBER X 10^-1
1.5
2
2.5
3
4
5
6
7
8
9
10
RUNS 4301-4329
REYNOLDS NUMBER X 10^-3

FIG. 47

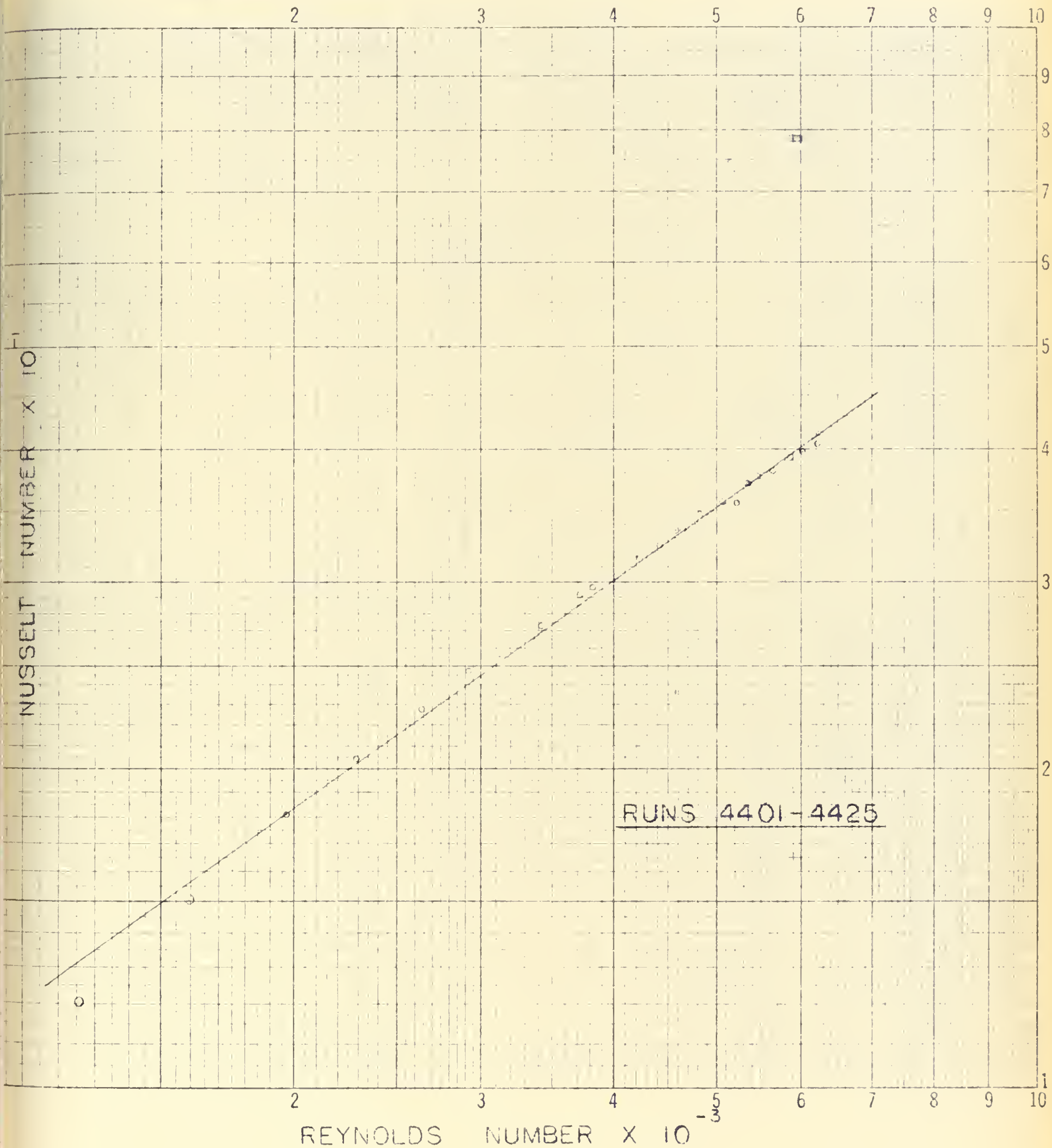


FIG. 48

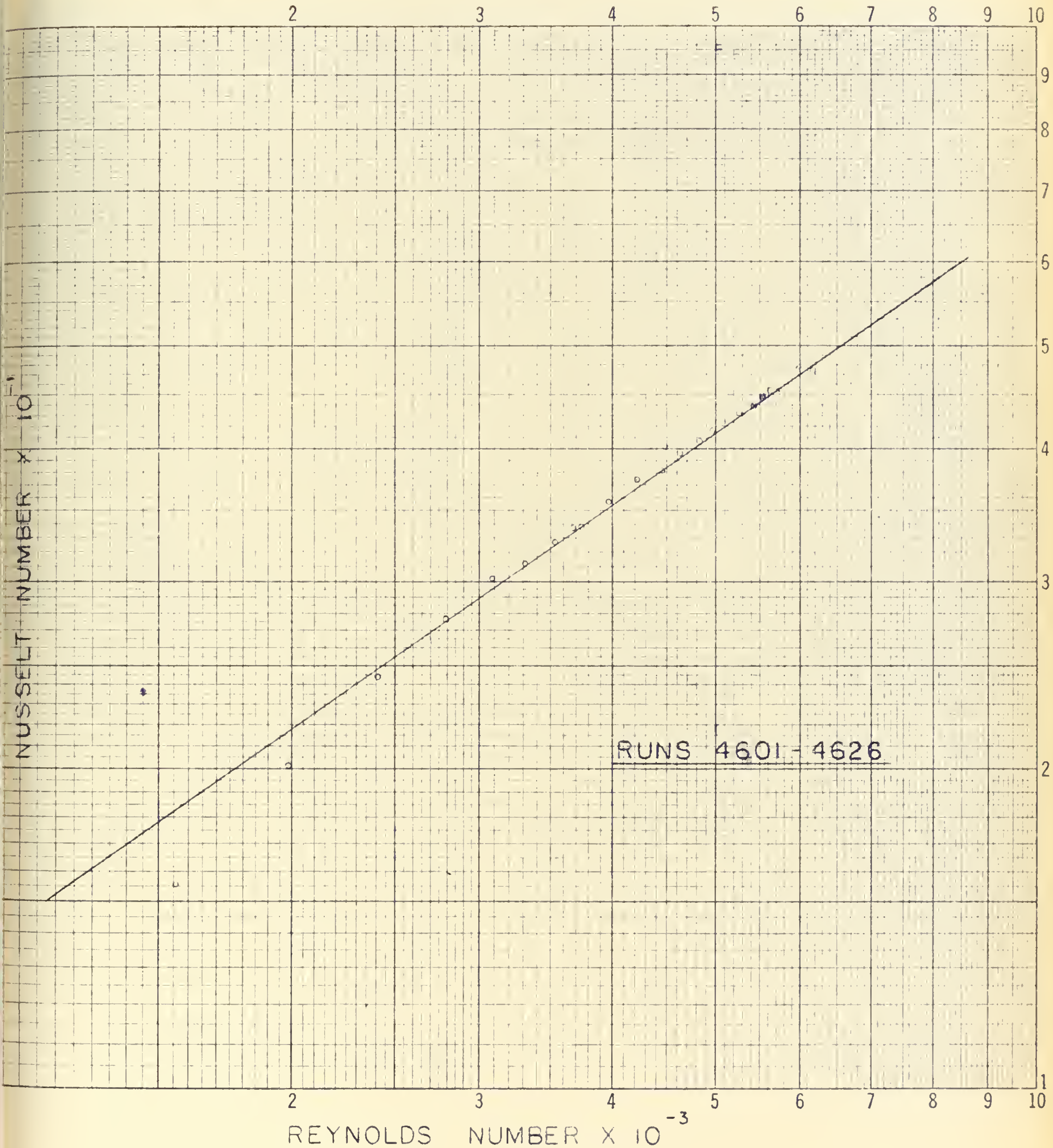
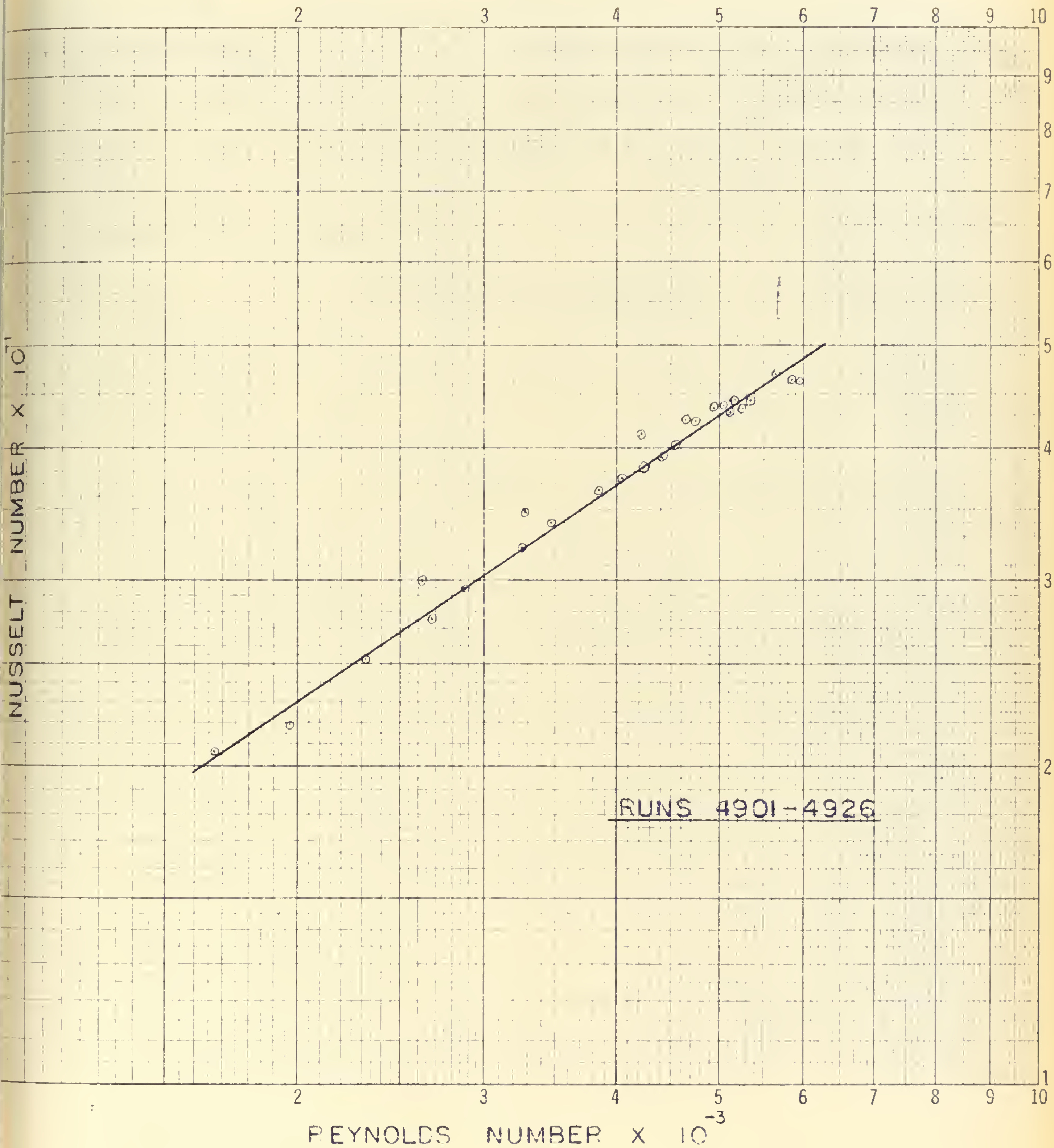

RUNS 4601 - 4626
NUSSELT NUMBER x 10⁻¹
REYNOLDS NUMBER X 10⁻³
2
3
4
5
6
7
8
9
10
1

FIG. 49



2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
NUSSELT NUMBER X 10^{1}
RUNS 4901-4926
REYNOLDS NUMBER X 10^{-3}

FIG. 50

APPENDIX H

Analysis of Frictional Resistance Results

Figures 51 thru 66 are plots of the computed friction factor versus Reynolds Number for individual geometries and angles of inclination. The uncertainty of data for Reynolds Numbers lower than 2500 was such that no points were used in the analysis. The process of curve fitting used was the method of least squares.

Least Squares Analysis

The frictional resistance data is fitted to an equation of the form:

$$\text{FRIFAC} = \text{CONST}\ (\text{CNRE})^{\text{EXPO}}$$

using the method of least squares. The logarithmic equivalent of the equation is taken:

$$\log \text{FRIFAC} = \log \text{CONST} + \text{EXPO} \log \text{CNRE}$$

and the normal equations developed by the usual method of multiplying by the coefficients of the variables CONST and EXPO in each case for each data point and summing. The normal equations so developed are:

$$\log \text{FRIFAC} = (\log \text{CNRE})\ \text{EXPO} + \text{THUMB} \log \text{CONST}$$

$$(\log \text{FRIFAC} \log \text{CNRE}) = (\log \text{CNRE})^2\ \text{EXPO} + (\log \text{CNRE}) \log \text{CONST}$$

These normal equations can be solved simultaneously for the log of CONST and EXPO:

$$\text{EXPO} = \frac{(\text{THUMB})\ (\log \text{FRIFAC})\ (\log \text{CNRE}) - (\log \text{CNRE})\ (\log \text{FRIFAC})}{(\text{THUMB})\ (\log \text{CNRE})^2 + (\log \text{CNRE})^2}$$

$$\text{XCON} = \frac{(\log \text{FRIFAC}) - (\log \text{CNRE})\ (\text{EXPO})}{(\text{THUMB})}$$

Then: CONST = antilog XCON

The parameters necessary for expression of friction factor as a function of Reynolds Numbers are thus developed.

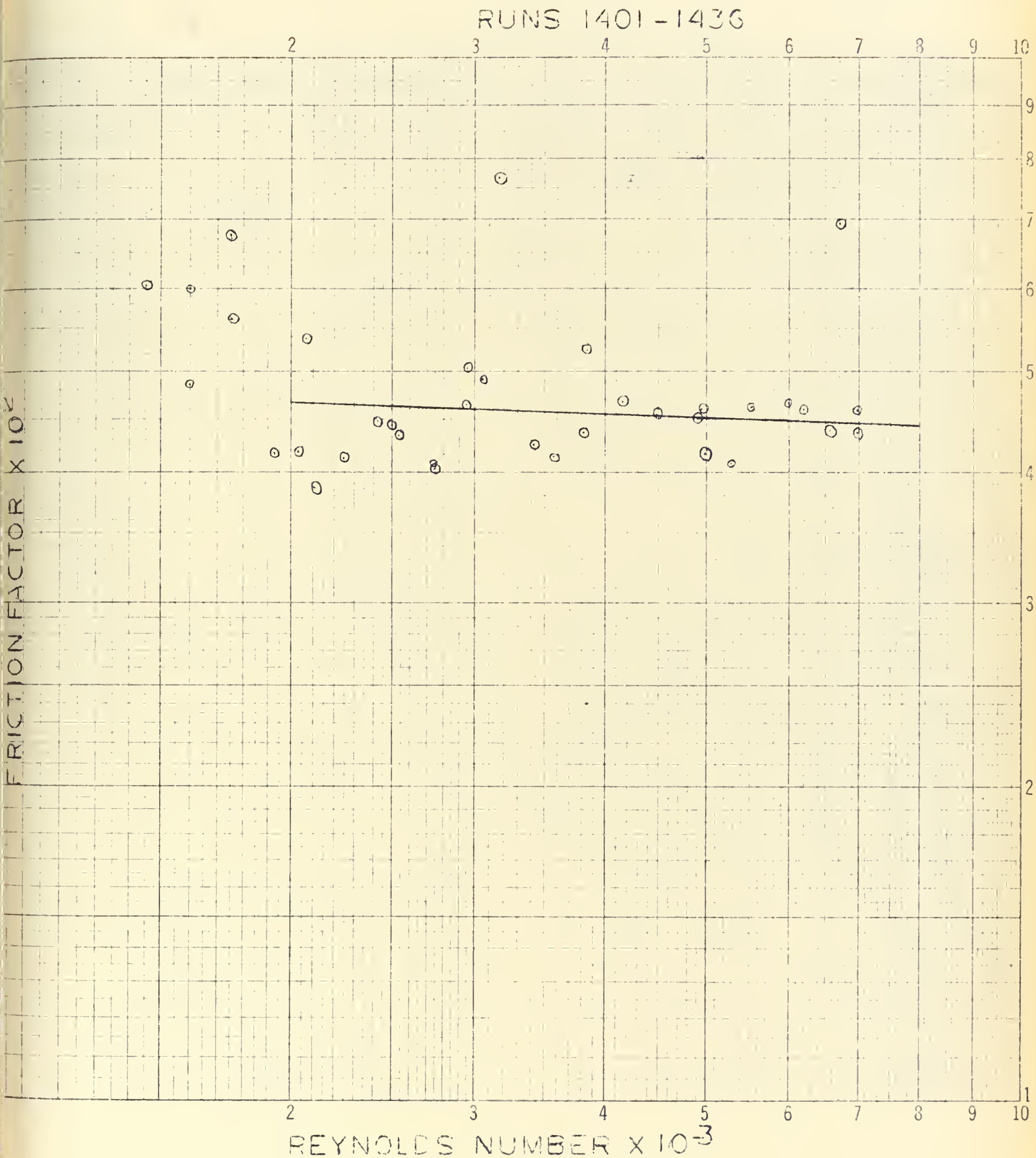

RUNS 1401-1436
2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
FRICTION FACTOR X 10^2
REYNOLDS NUMBER X 10^{-3}

FIG. 51

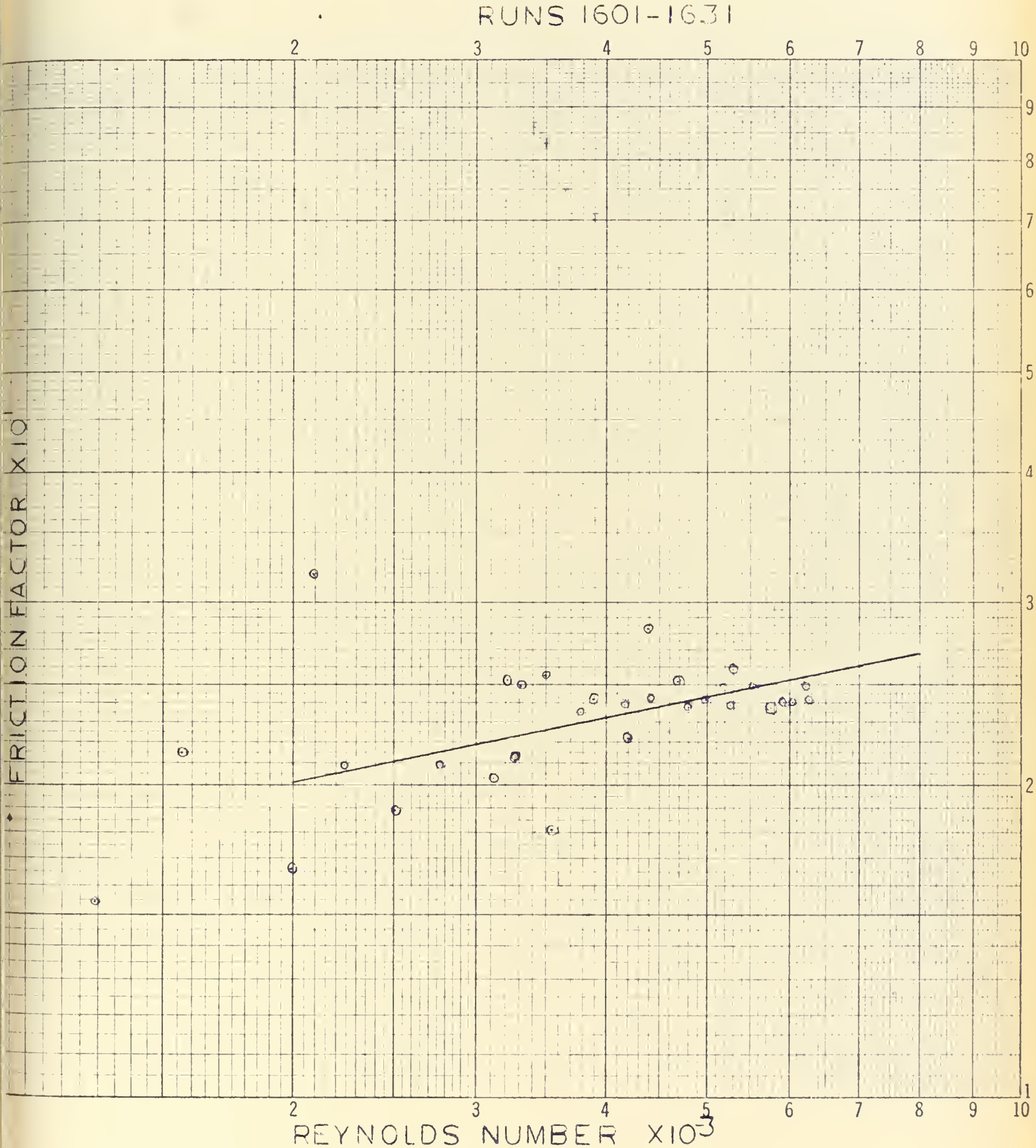

RUNS 1601-1631
FRICTION FACTOR X10
REYNOLDS NUMBER X10
2
3
4
5
6
7
8
9
10
1

FIG. 52

RUNS 1701-1716

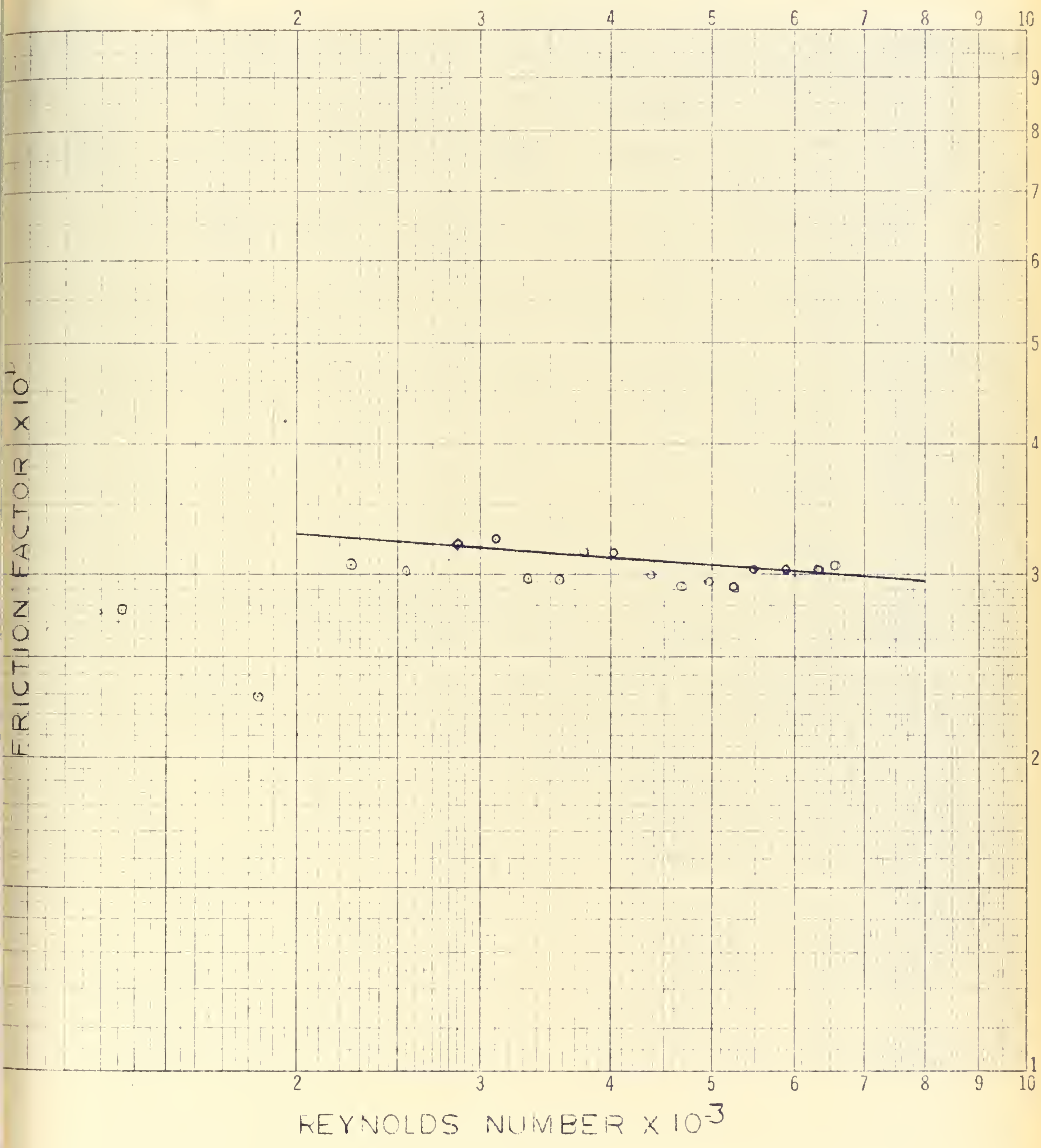


FIG. 53

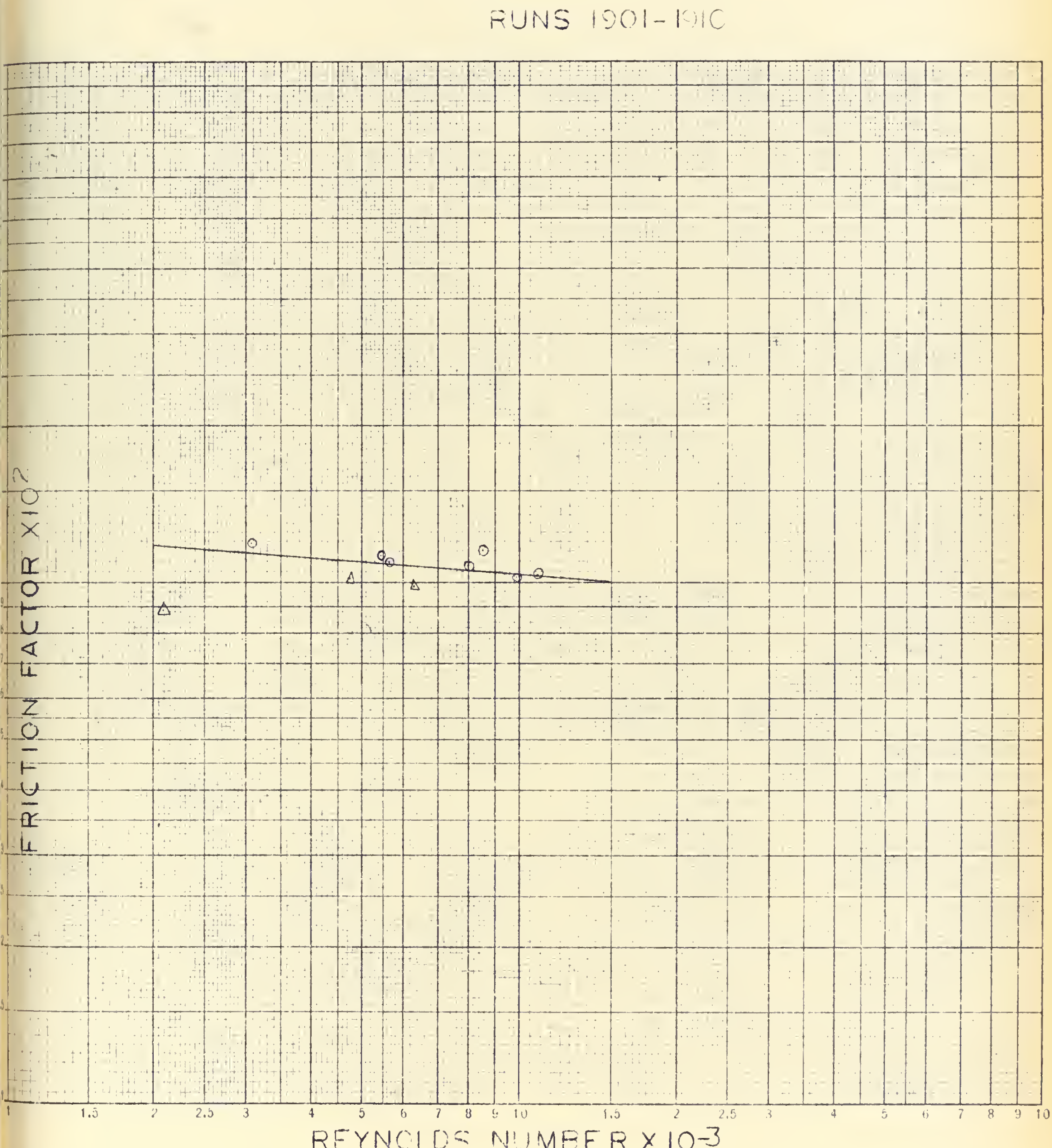

RUNS 1901-191C
FRICTION FACTOR X10²
1
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
4
5
6
7
8
9
10
REYNOLDS NUMBER X 10⁻³

FIG 54

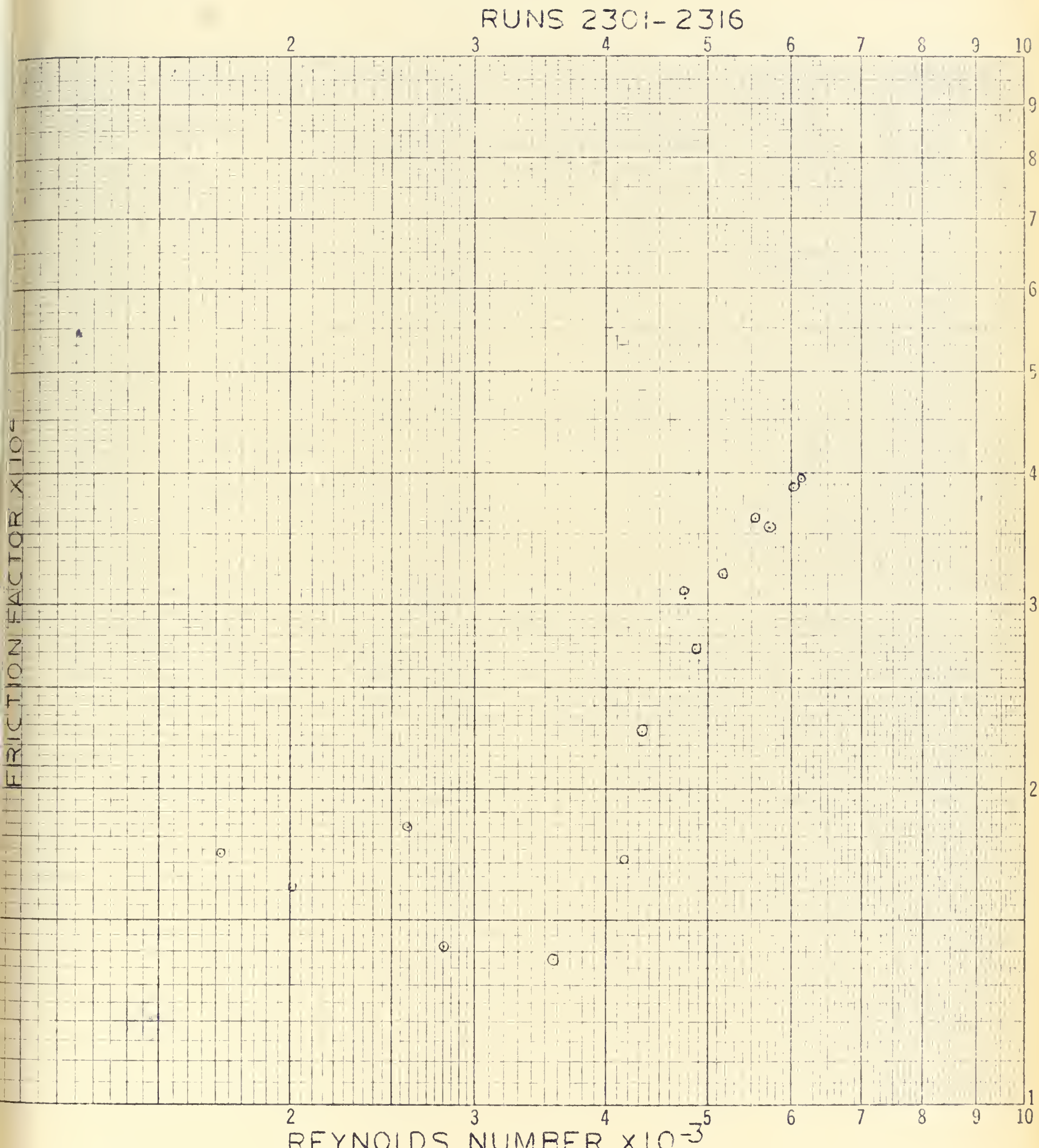

RUNS 2301-2316
FRICTION FACTOR X 10^4
REYNOLDS NUMBER X 10^-3
2
3
4
5
6
7
8
9
10
1

FIG 55

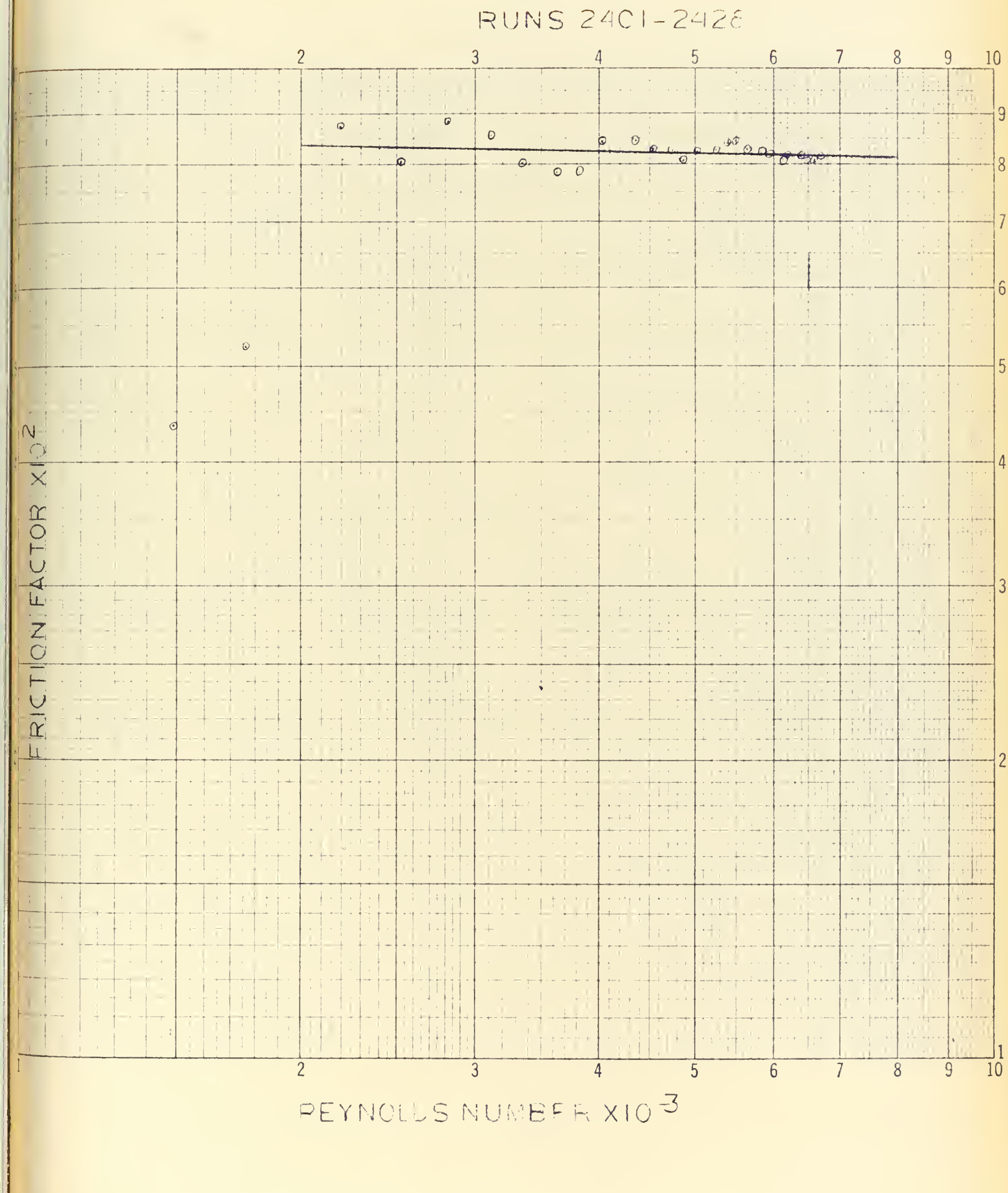

RUNS 2401-2426
2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
1
FRICTION FACTOR X10^2
REYNOLDS NUMBER X10^{-3}

FIG 56

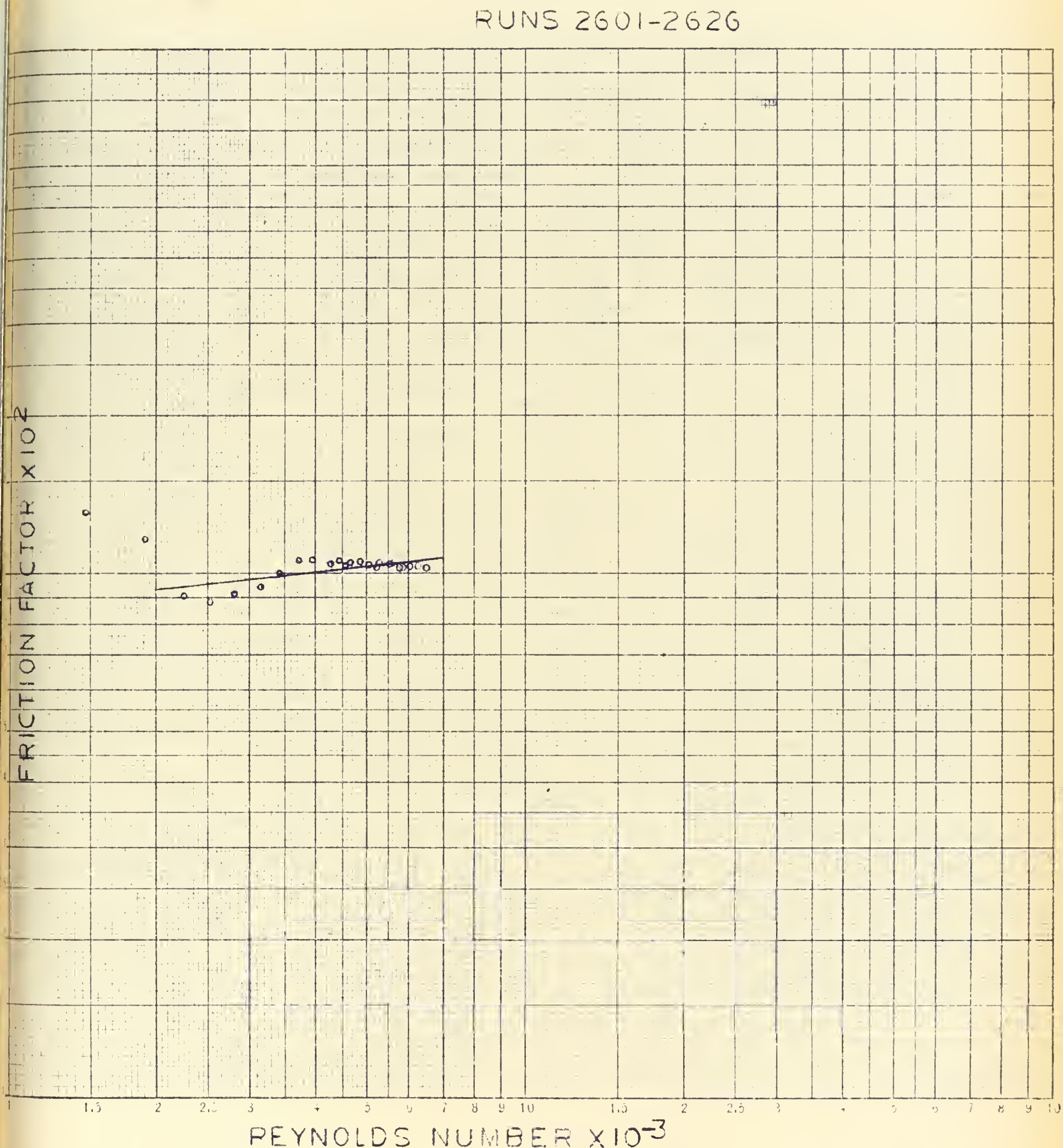

RUNS 2601-2626
FRICTION FACTOR X10^2
1
1.5
2
2.5
3
4
5
6
7
8
9
10
1.5
2
2.5
3
REYNOLDS NUMBER X10^-3

FIG 56

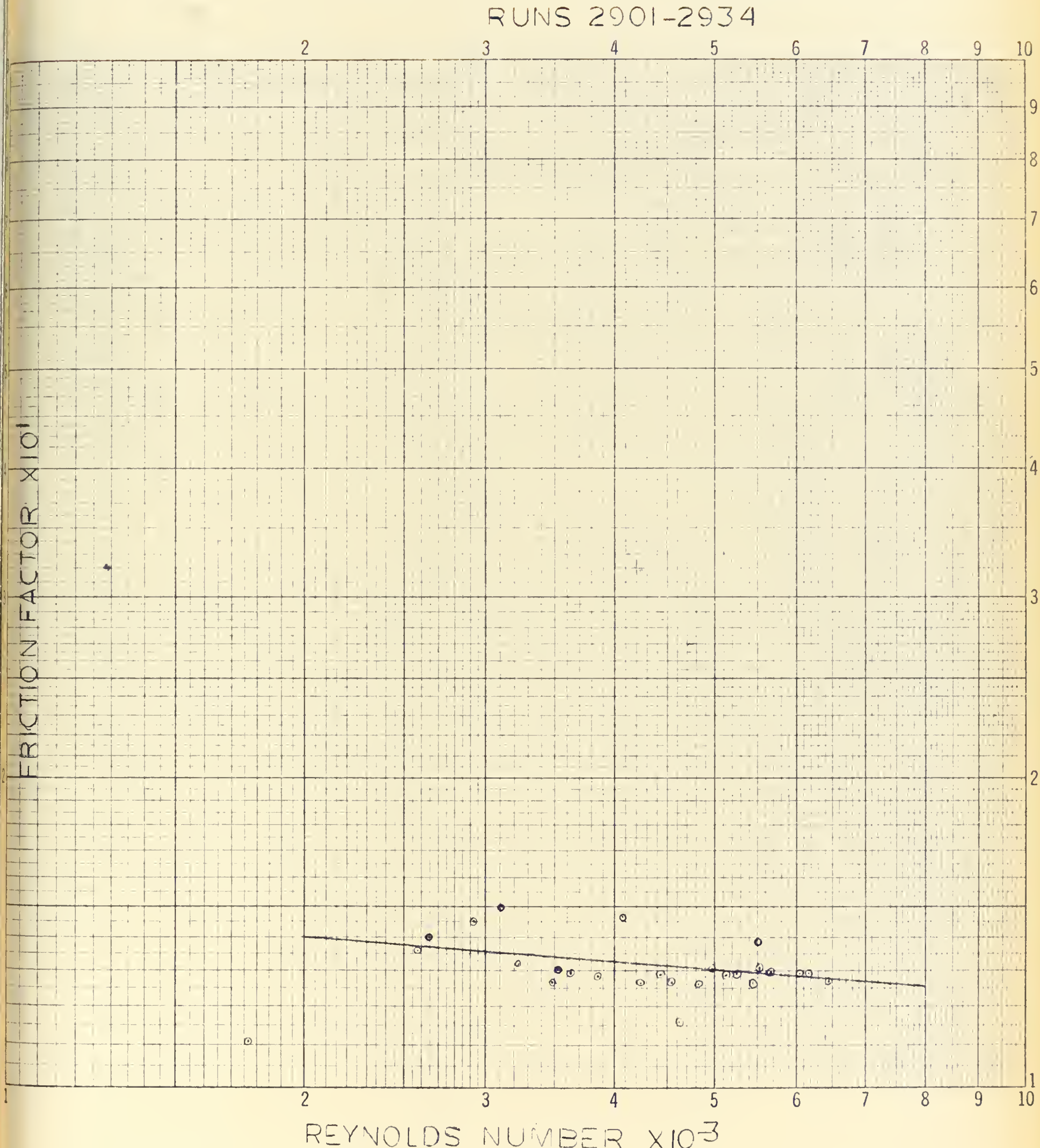


FIG 58

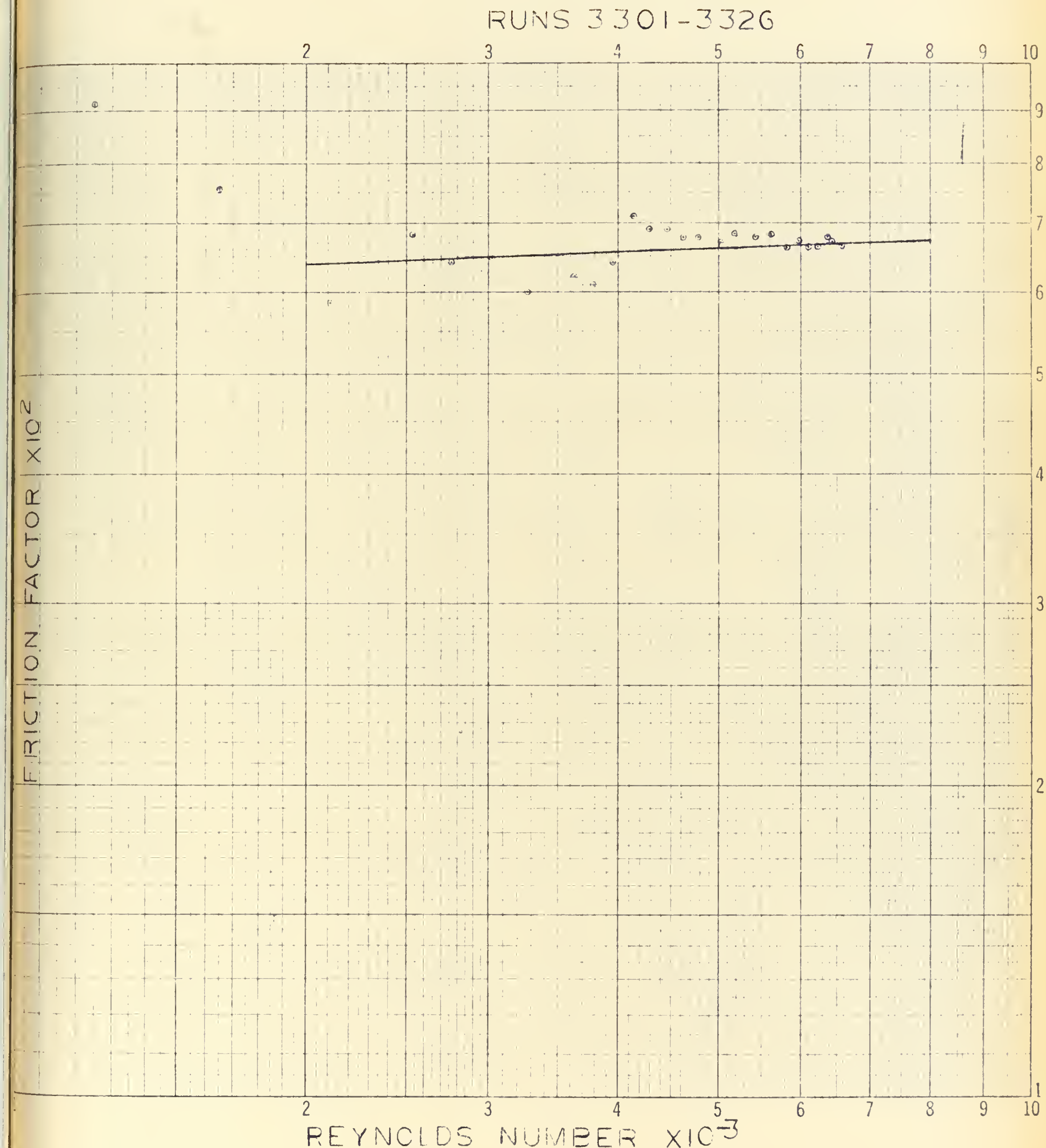

RUNS 3301-3326
2
3
4
5
6
7
8
9
10
FRICTION FACTOR X10²
REYNOLDS NUMBER X10⁻³

FIG 59

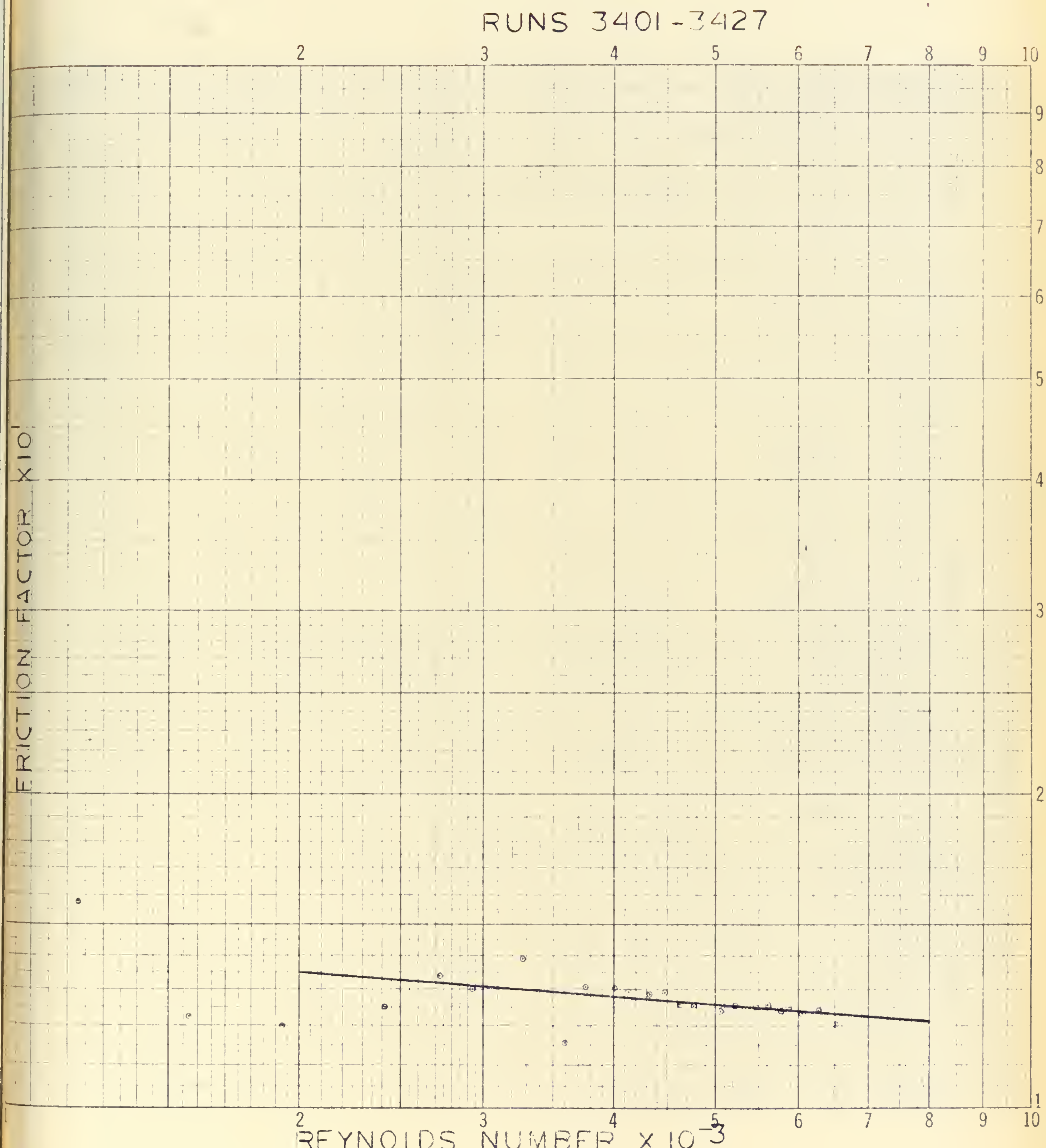


FIG 60

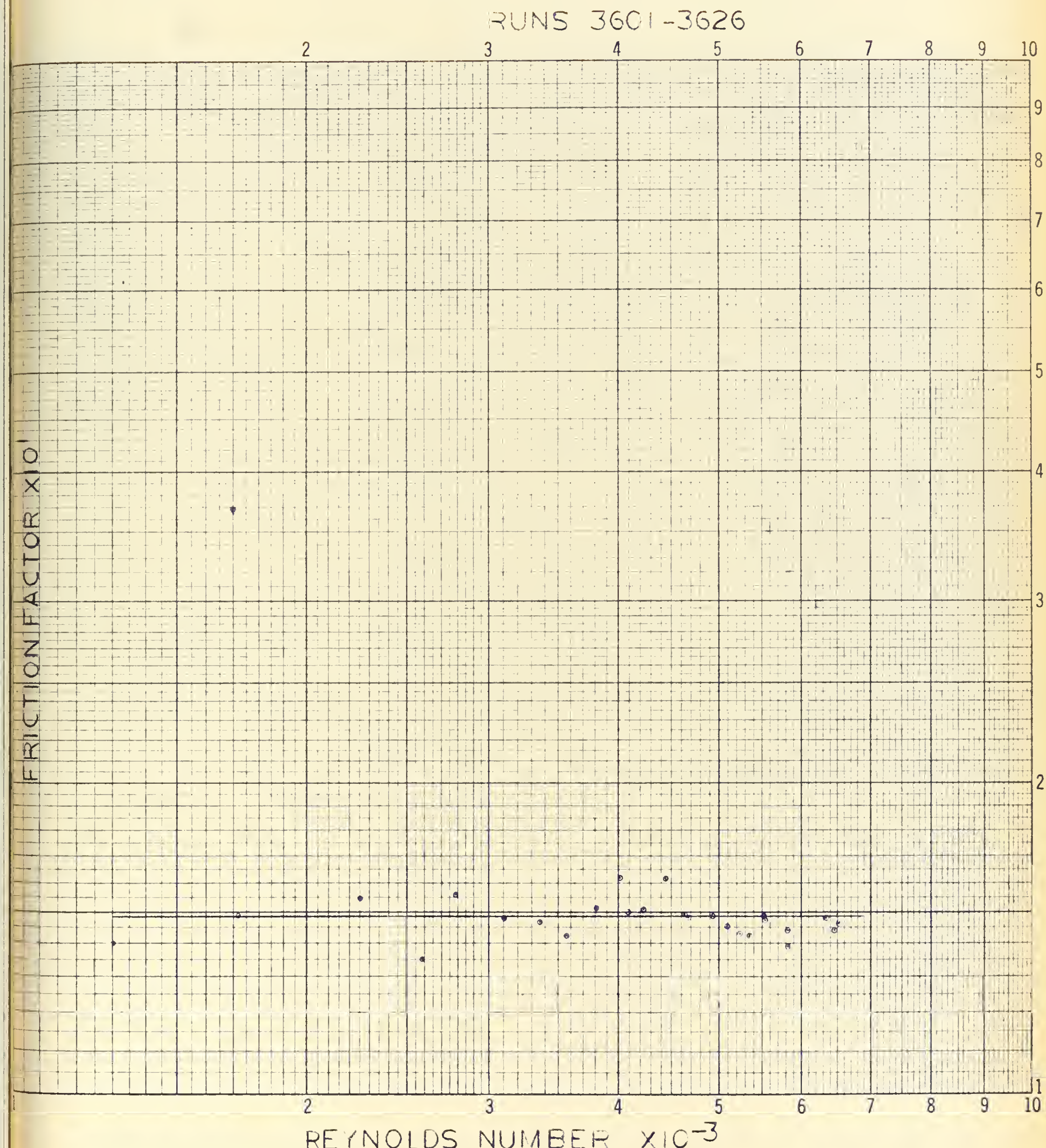
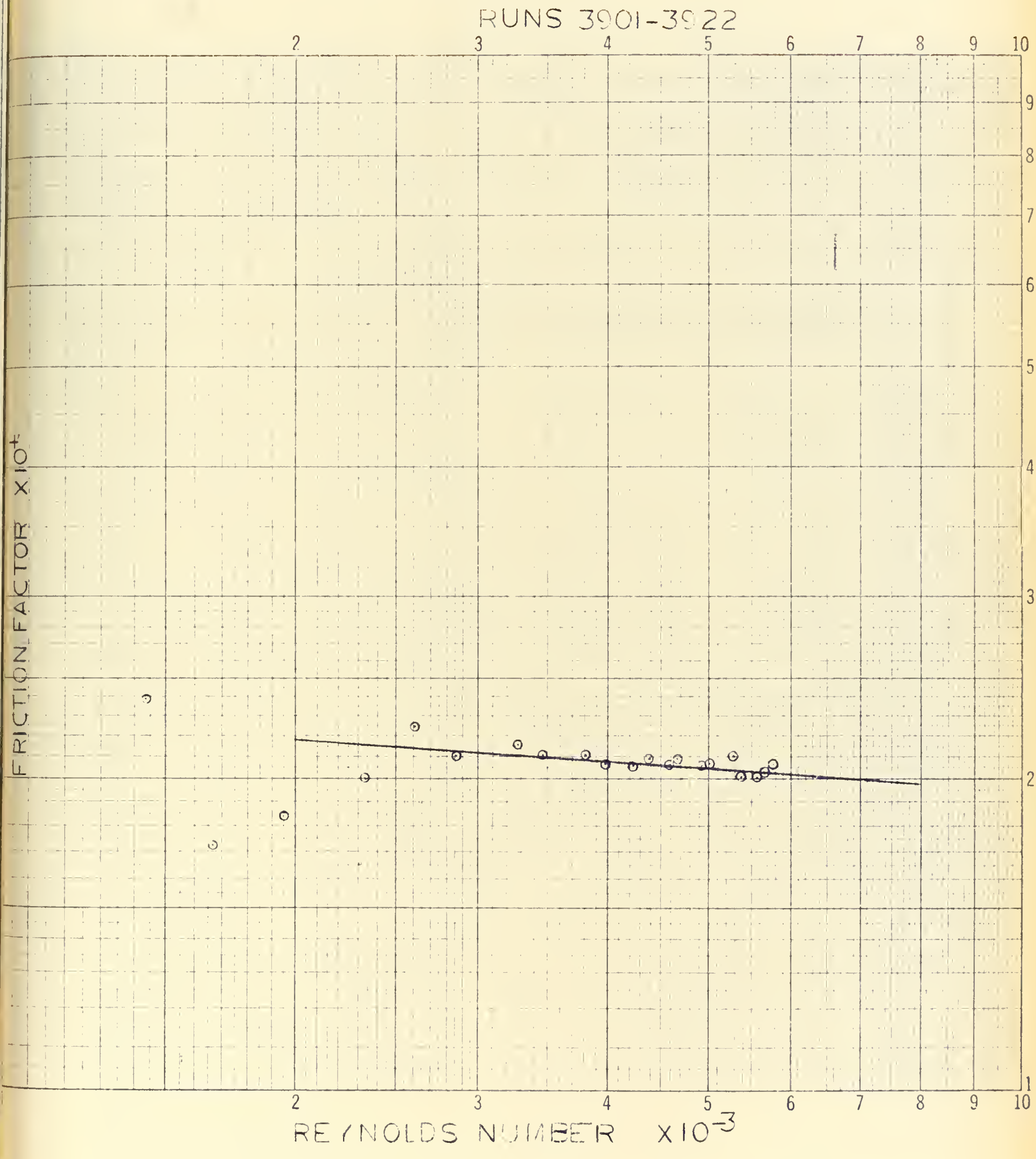

RUNS 3601-3626
FRICTION FACTOR X10^{1}
REYNOLDS NUMBER X10^{-3}
2
3
4
5
6
7
8
9
10
1

FIG 61



RUNS 3901-3922
2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
FRICTION FACTOR X 10⁴
REYNOLDS NUMBER X 10⁻³

FIG. 62

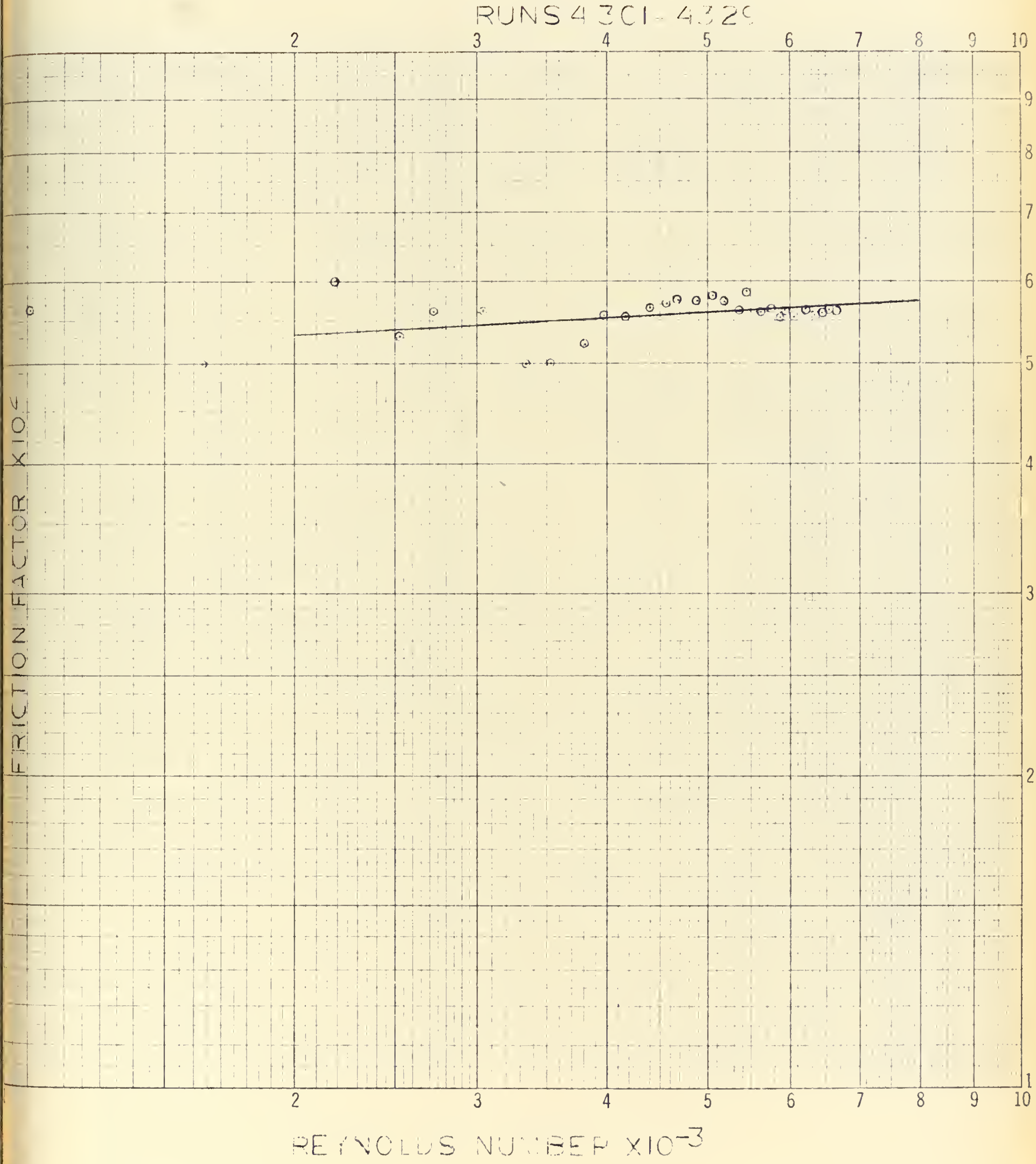


FIG. 63

RUNS 4401 - 4425

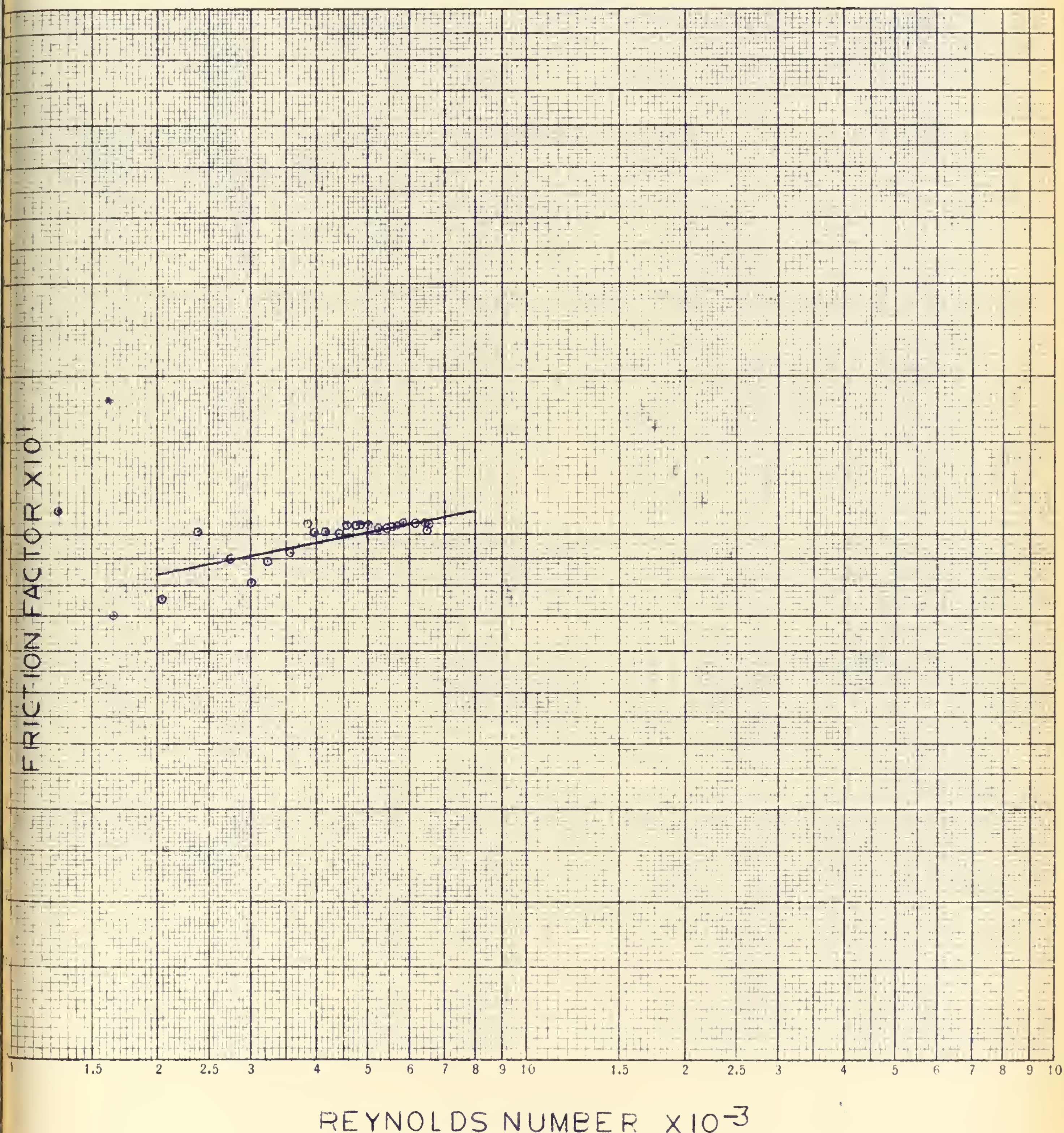


FIG 64

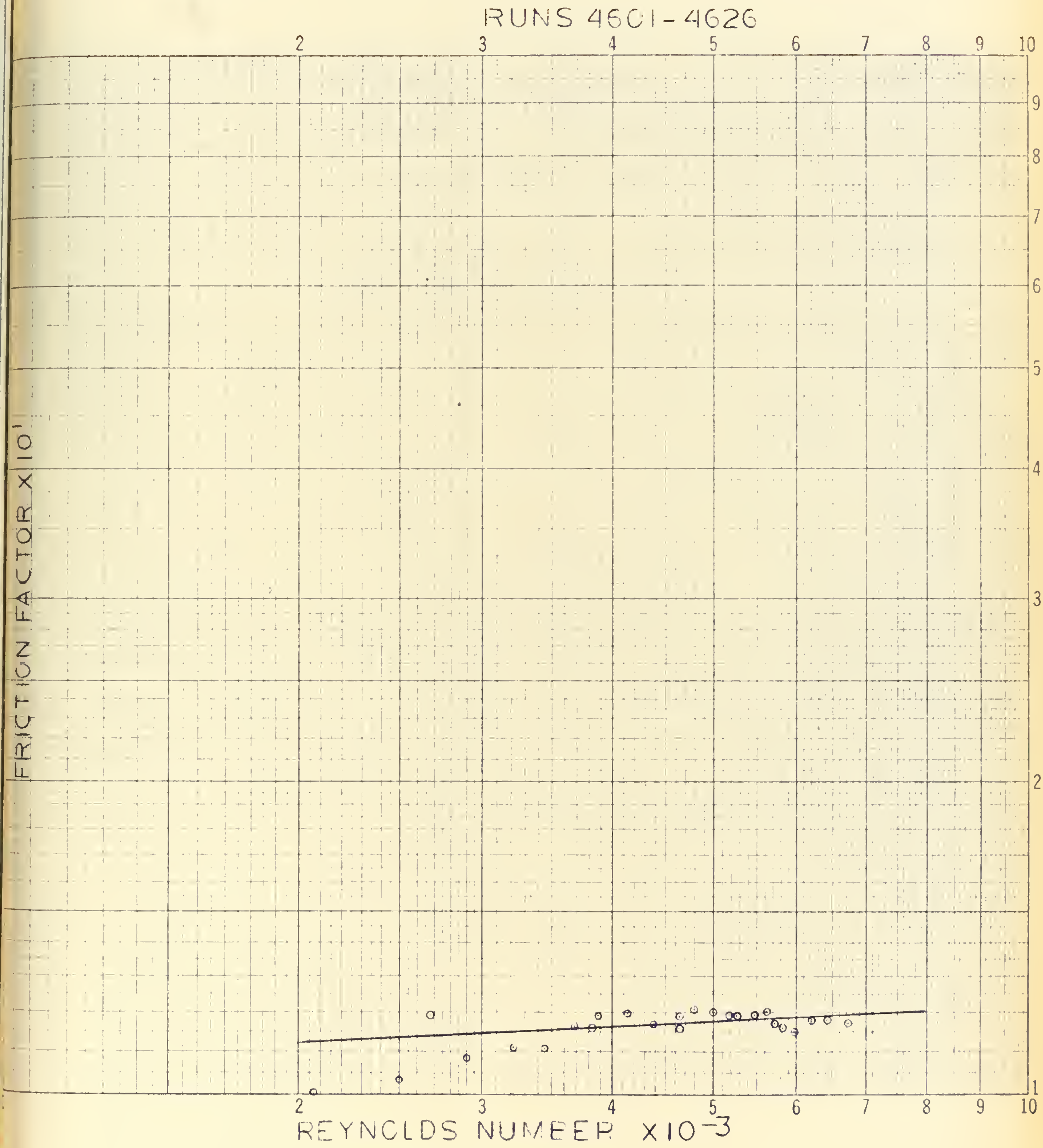

RUNS 4601-4626
FRICTION FACTOR X 10'
REYNOLDS NUMBER X10^{-3}
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8
9

FIG 65

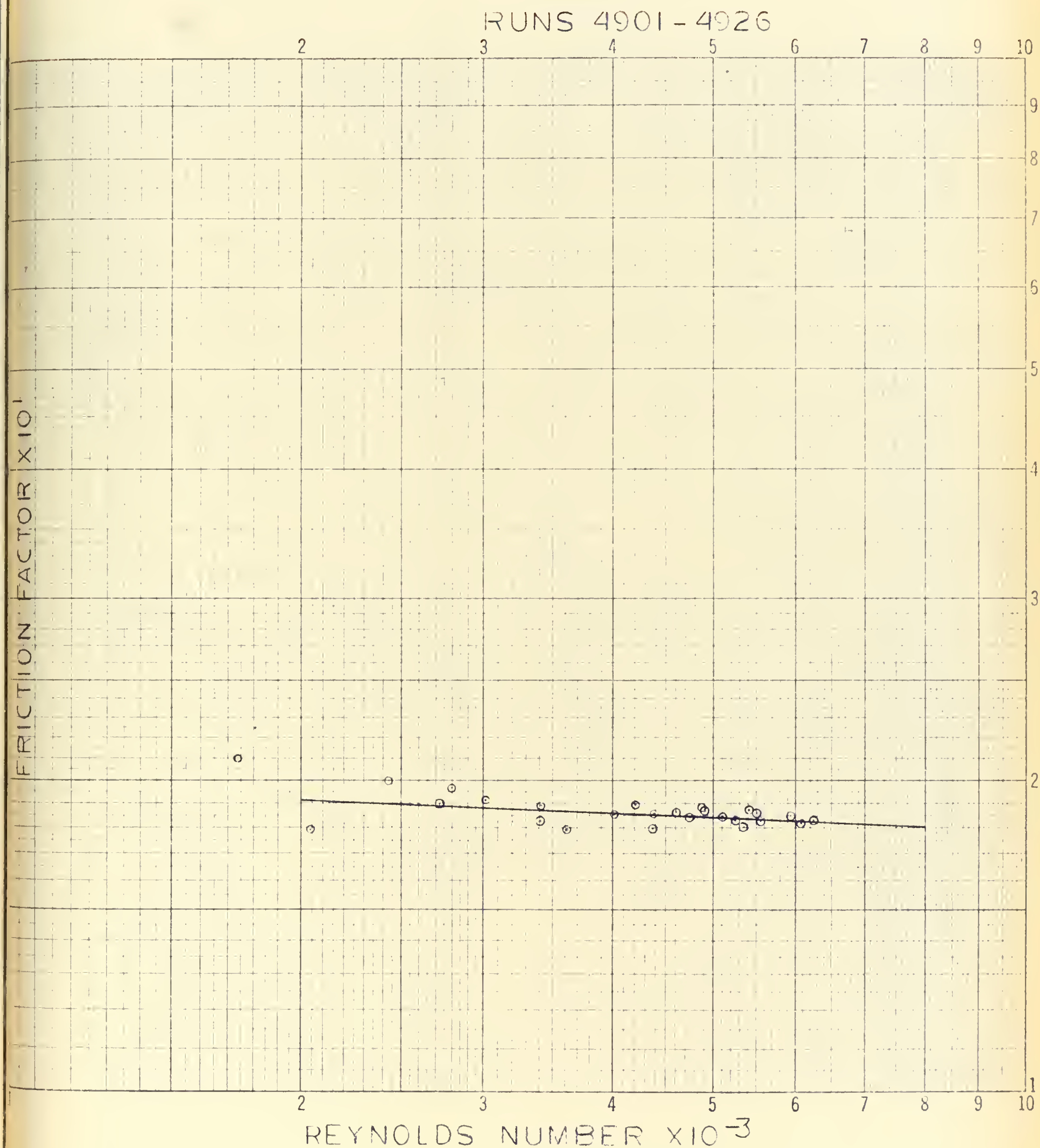

RUNS 4901-4926
2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3
2
1
FRICTION FACTOR X10'
REYNOLDS NUMBER X10^-3

FIG 66

Frictional Resistance Analysis Computer Program Description

The computer program described herein is a FORTRAN II program compatible with the IBM 1620 data processing system. The function of the program is to fit a curve whereby friction factor is expressed as a power of Reynolds Number using the method of least squares. While variable names, input, output and format statements are particularized to the problem at hand the method is completely general and can be used in any application where a logarithmic least squares analysis is desired with only minor program modifications. It would be possible to include this program in the basic data reduction program to permit reduction and analysis in one computation.

Overall control of the program is by a DO loop indexed by the number of sets of data being analyzed. For each data set another DO loop indexed by the number of data points in the data set controls the calculations. For each data set the program first sets the summations equal to NUMB, then accepts as input the friction factor and Reynolds number for the first data point. The natural logarithms of the input quantities, the product of the two logarithms and the square of the logarithm of Reynolds Number are computed. The summations necessary to determine the coefficients of the normal equations are computed with variable names being changed as necessary for proper program operation. The program then loops to repeat the calculations described above for each data point until all data points in the set have been calculated. The values of

the exponent, EXPO, and the natural logarithm of the coefficient, XCON can then be computed for the particular data set. As no antilogarithm function is available in the FORTRAN II library the value of the coefficient, CONST, is calculated by:

$$CONST = E^{XCON}$$

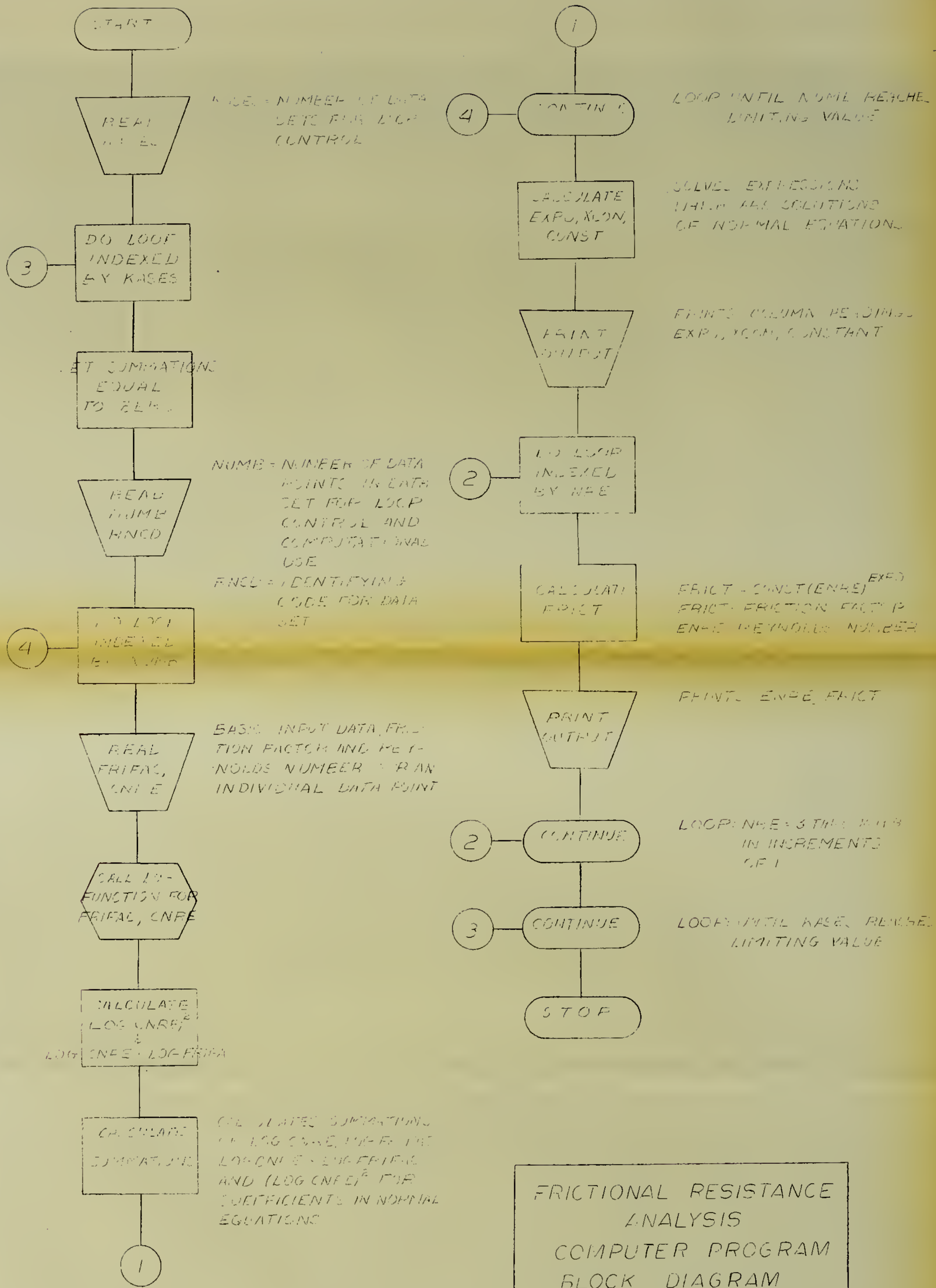
When the values of the coefficient and exponent have been determined an output consisting of these quantities plus an identifying code, and the logarithm of the coefficient is printed.

The quantities which have been computed so far represent the parameters necessary for expressing friction factor as a function of Reynolds Number for a particular geometry and angle of inclination. In order to correlate the values calculated with the equation developed using these parameters with test results, values of Reynolds Number from three thousand to eight thousand are inserted into the equation and the corresponding friction factor computed. The results are printed.

When the calculation of the friction factors is completed the program loops to perform the calculations for the next data set until the limiting index is reached.

A program block diagram, listing, sample output, and output summary follow.

Computations using this program were made at C.W. Post College; data was prepared at Webb Institute.



FRICTIONAL RESISTANCE ANALYSIS COMPUTER PROGRAM BLOCK DIAGRAM

FIG. 67

```
C     FORTRAN TWO PROGRAM TO CORRELATE FRICTIONAL RESISTANCE DATA BY
C     LEAST SQUARES
    1 FORMAT(I4)
    2 FORMAT(2I4)
    3 FORMAT(F9.6,2X,F9.2)
    4 FORMAT(1H1,2X,57HRUN CODE      EXPONENT        CONSTANT      LOG(CONS
P    1TANT)     )
    5 FORMAT(1H0,4X,I2,7X,F10.6,5X,F10.6,5X,F10.6)
    9 FORMAT(1H0,6X,F8.2,13X,F9.6)
   10 FORMAT(1H0,2X,37HREYNOLDS NUMBER       FRICTION FACTOR )
      READ 1,KASES
      DO 7 MA=1,KASES
      SUMFLN=0.0
      SUMREL=0.0
      SMSRG=0.0
      SMFGRE=0.0
      READ 2,NUMB,RNCD
      DO 6 NU=1,NUMB
      READ 3,FRIFAC,CNRE
      FLG=LOGF(FRIFAC)
      RELG=LOGF(CNRE)
      FLGREL=FLG*RELG
      SRELG=RELG**2
      SUMFLG=SUMFLN+FLG
      SUMFLN=SUMFLG
      SMRELG=SUMREL+RELG
      SUMREL=SMRELG
      SMSREL=SMSRG+SRELG
      SMSRG=SMSREL
      SMFLRL=SMFGRE+FLGREL
      SMFGRE=SMFLRL
    6 CONTINUE
      THUMB=NUMB
      EXPO=(THUMB*SMFGRE-SUMREL*SUMFLN)/(THUMB*SMSRG-(SUMREL**2))
      XCON=((SUMFLN-(SUMREL*EXPO))/THUMB)
      CONST=2.71828**XCON
      PRINT 4
      PRINT 5,RNCD,EXPO,CONST,XCON
      PRINT 10
      DO 8 NRE=3,8
      DNRE=NRE
      ENRE=DNRE*(1.0E3)
      FRICT=CONST*(ENRE**EXPO)
      PRINT 9,ENRE,FRICT
    8 CONTINUE
    7 CONTINUE
      STOP
      END
```

RUN CODE	EXPONENT	CONSTANT	LOG(CONSTANT)
43	.060968	.033258	-3.403455

REYNOLDS NUMBER	FRICTION FACTOR
3000.00	.054187
4000.00	.055145
5000.00	.055901
6000.00	.056526
7000.00	.057059
8000.00	.057526

STOP

Summary of Frictional Resistance Analysis

Run Code	Exponent	Constant
14	-0.043053	0.065543
16	0.196590	0.045465
17	-0.045756	0.445318
19	-0.079225	0.214984
24	-0.024007	0.100758
26	-0.119514	0.037337
29	-0.081586	0.261858
33	0.057896	0.040784
34	-0.089713	0.270171
36	-0.028274	0.187797
39	-0.086865	0.431623
43	0.060968	0.033258
44	0.210122	0.017001
45	0.053331	0.074656
49	-0.055798	0.297399

Run Code	14	16	17	19
Reynolds Number	Friction Factor	Friction Factor	Friction Factor	Friction Factor
3000	0.046433	0.219407	0.308722	0.114006
4000	0.045861	0.232174	0.304685	0.111437
5000	0.045422	0.242585	0.301590	0.109484
6000	0.045067	0.251438	0.299084	0.107914
7000	0.044769	0.259174	0.296982	0.106604
8000	0.044513	0.266068	0.295173	0.105482

Run Code	24	26	29
Reynolds Number	Friction Factor	Friction Factor	Friction Factor
3000	0.083138	0.097209	0.136263
4000	0.082566	0.110610	0.133102
5000	0.082125	0.103329	0.130701
6000	0.081766	0.105605	0.128771
7000	0.081464	0.107569	0.127162
8000	0.081204	0.109299	0.125784

Run Code	33	34	36	39
Reynolds Number	Friction Factor	Friction Factor	Friction Factor	Friction Factor
3000	0.064834	0.131732	0.149752	0.215310
4000	0.065923	0.128376	0.148539	0.209996
5000	0.066780	0.125831	0.147605	0.205965
6000	0.067489	0.123790	0.146846	0.202728
7000	0.068094	0.122090	0.146207	0.200032
8000	0.068622	0.120636	0.145656	0.197725

Run Code	43	44	46	49
Reynolds Number	Friction Factor	Friction Factor	Friction Factor	Friction Factor
3000	0.054187	0.091434	0.114421	0.190248
4000	0.055145	0.097132	0.116190	0.187219
5000	0.055901	0.101795	0.117581	0.184902
6000	0.056526	0.105770	0.118730	0.183031
7000	0.051059	0.109252	0.119710	0.181463
8000	0.057526	0.112361	0.120568	0.180116

Friction Factor (f)

Run Code	Re = 3000	Re = 4000	Re = 5000	Re = 6000	Re = 7000	Re = 8000
14	0.046433	0.045861	0.045422	0.045067	0.044769	0.044513
16	0.219407	0.232174	0.242585	0.251438	0.259174	0.266068
17	0.308722	0.304685	0.301590	0.299084	0.296932	0.295173
19	0.114006	0.111437	0.109484	0.107914	0.106604	0.105482
24	0.083138	0.082566	0.082125	0.081766	0.081464	0.081204
26	0.097209	0.110610	0.103329	0.105605	0.107569	0.109299
29	0.136263	0.133102	0.130701	0.128771	0.127162	0.125784
33	0.064834	0.065923	0.066780	0.067489	0.068094	0.068622
34	0.131732	0.128376	0.125831	0.123790	0.122090	0.120636
36	0.149752	0.148539	0.147605	0.146846	0.146207	0.145656
39	0.215310	0.209996	0.205965	0.202728	0.200032	0.197725
43	0.054187	0.055145	0.055901	0.056526	0.057059	0.057526
44	0.091434	0.097132	0.101795	0.105770	0.109252	0.112361
46	0.114421	0.116190	0.117581	0.118730	0.119710	0.120568
49	0.190248	0.187219	0.184902	0.183031	0.181963	0.180116